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Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C.

August 17, 1921

A STUDY OF THE FACTORS
AFFECTING TEMPERATURE CHANGES
IN THE CONTAINER DURING THE
CANNING OF FRUITS AND
VEGETABLES

By

C. A. MAGOON and C. W. CULPEPPER
Office of Horticultural and Pomological Investigations

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BASIS OF THE STUDY.

Successful preservation of foods by canning is due primarily to the fact that in the processing, or cooking, the bacteria and other microorganisms which cause spoilage are destroyed. Since the elimination of these microorganisms is dependent upon the use of heat as a sterilizing agent, it becomes of paramount importance to know just what temperatures and processing periods will destroy them. If uniformly good results are to be expected, a sufficient degree of heat must penetrate to all parts of the can or jar, and must

¹ The manuscript of this bulletin was submitted for publication on February 27, 1920; circumstances of an incidental character interfered with its early issue.

be maintained long enough to render all microorganisms harmless. Before an accurate judgment as to the proper cooking period can be formed it is necessary to know how long a time is required for the food at the center of the container to reach the temperature of the retort or water bath in which it is being processed.

In the work here reported upon attention has been centered upon these time-temperature relations, and the purpose has been to bring to light underlying principles rather than to lay down definite rules of procedure, for specific recommendations should be preceded by carefully demonstrated facts.

The diagrams and other data presented are based upon the results of more than 600 tests made during the year 1919. All vegetables used were grown especially for this work on the experimental farm at Arlington, Va., and these, together with such fruits as were used, were handled fresh from the fields. In the details of preparation of these materials for the tests, no attempt was made to follow any particular set of rules hitherto laid down. Rather, an endeavor was made to illustrate average conditions, and the results of this experimentation are offered in the hope that they may be of service to other workers in this field.

REVIEW OF THE LITERATURE.

Attention was first called to the importance of the rate of heat penetration into cans of food material during processing by Prescott and Underwood (12, 7)² in 1898. In a study of the cause of souring in canned corn these authors went thoroughly into the bacteriology of the problem and isolated and studied the causal organisms found. A long series of experiments was undertaken involving more than 400 tests, in which, by the use of maximum thermometers sealed into the cans, the length of time required for the temperature at the center of the cans of corn to reach that of the retort was determined. Their results showed that, whatever the temperature of processing, the center of the cans of corn reached the temperature of the retort in approximately the same time. This observation has been made by later investigators and accords with the findings reported in this work.

These workers found that in processing corn at 118.8° C. for 1 hour 55 minutes were required for the center of the 2-pound can to reach the temperature of the retort, and they concluded that in processing for 1 hour the maximum temperature was maintained for only 5 minutes. They failed to take into consideration, however, the fact that in substances of heavy consistency, such as corn, the temperature is maintained for a considerable time at or very close to the temperature of the retort after removal from it to the air.

² Serial numbers in parentheses refer to "Literature cited" at the end of this bulletin.

In the various discussions of their work the fact was also pointed out that the quantity of liquor added to corn affects the rate at which heat penetrates into it.

Duckwall (9) in 1905 reported similar experiments with peas. He also found that, regardless of the temperature of processing, the temperature in the can reached that of the retort in the same length of time.

In the same year Belser (1), working upon the spoilage of canned foods, also reported upon studies of the time-temperature relations in the cans. He worked with peas, beans, mixed vegetables, carrots, tomato puree, comfrey, spinach, sauerkraut, cherries, and apple pulp. Maximum temperatures during the processing were obtained by the use of maximum thermometers, and numerous tables of results were given. These show, as might be expected, considerable variations in the temperatures reached by the different foods when handled under identical conditions. Belser pointed out the great importance of knowing the speed at which the heat penetrates to the center of the cans and performed several experiments with peas and beans to determine this. The method of preparation of material, the nature of the containers, and the details of his work were such as to make direct comparisons with American work impossible.

Haselhoff and Bredemann (10) in their report of investigations upon the decomposition of canned foods (1906) referred briefly to an apparently unpublished work of Huber in which attention was called to the fact that during the processing of certain food products the temperature inside the containers often did not reach that of the bath or retort in which they were processed.

Kochs and Weinhausen (11) carried on experiments (1906-7) with cabbage, carrots, asparagus, apple sauce, and peas. The methods employed correspond closely to those of Belser (1), and their results are not comparable with the findings of American workers. They pointed out that the rate of heat penetration is dependent upon the firmness of the pack and the proportion of liquid present. They worked also with glass and stoneware containers.

Bitting (2), in 1912, described two methods for the determination of the rate of heat penetration in cans of food. One method made use of long-stemmed thermometers held with the bulb at the center of the cans by means of a special device whereby direct reading of the temperature was made possible. The second method made use of thermocouples. For the higher temperature chlorid baths were used. Bitting pointed out that in substances having plenty of free liquid the heat passed in much more rapidly than in substances of heavy consistency and with less liquid. The advantages of agitation in shortening the cooking period were emphasized. No experimental data were given, however.

Zavalla (14), in 1916, published tables of experiments with cherries, apricots, peaches, and pears. He found the time required for the temperature to reach 212° F. at the center of the can processed in boiling water to vary with the different fruits and explained his findings as due to the difference in their heat conduction. He also stated that the concentration of the sirup seemed to exert a definite action upon the rapidity with which the heat penetrated to the center of the can. His conclusions agree with the results of the present work, but the tables given are not sufficiently clear to make direct comparisons possible.

Bitting and Bitting (4), using both thermometers and thermocouples, made numerous tests with various fruits and vegetables (1917). They worked out experimentally the effect of agitation upon the rate of heat penetration, and found that about 12 revolutions per minute gave the most satisfactory results in getting the heat to the center of the cans without injuring delicate fruits and berries. Numerous diagrams were given, showing the results of processing various substances with the cans held stationary and also rolled. These investigators stated that the minimum time was required to bring the temperature of the can to that of the surrounding bath in those foods in which the proportion of liquid allowed free convection and that mashed sweet potatoes required about the maximum. Furthermore, they found that in sweet potatoes the temperature at the center of the can rarely reaches to within 10 degrees centigrade of that of the retort or bath during the ordinary processing. Their results are entirely in accord with the conclusions drawn from the present work.

Denton (8) in 1918 reported the results of two tests with carrots in which the influence of closeness of pack on heat penetration was considered.

During the same year (1918) Bovie and Bronfenbrenner (5) described a thermoelectric apparatus for measuring the rate of heat penetration in foods during the canning process. The apparatus allowed the determination of the temperature at various parts of the can at any time during the processing by means of thermocouples. Measurements closer than 1° C. were not attempted, however, and the "constant" junction was placed in the autoclave close to the test can. Inasmuch as 15 minutes were required to obtain an equilibrium of pressure and therefore temperature, the "constant" junction did not become constant until 15 minutes after the can was placed in the retort.

While this apparatus would be satisfactory, perhaps, for substances like baked beans and sweet potatoes, it would be entirely unsuited for the determination of temperature changes in cans of such products as string beans and peas, in which the temperature in

the can attains or approaches closely that of the retort in less than 15 minutes. The prime advantage of the apparatus as described by these authors is that it allows the determination of the temperatures at various parts of the can at any time, thus giving a true idea of the rate of heat flow within the material itself. It is obvious, however, that the readings obtained under the conditions described are no more accurate than may be obtained by the direct reading of the mercury thermometer.

Castle (6) in 1919 called attention to the fact that the depth of the water bath about the jars directly affects the rate of change of temperature at the center of the containers, the shallower the bath the slower the rate of change. She also pointed out that in the intermittent process the first cooking may so compact the material that the heat penetrates more slowly in the second and third heatings. This was found to be true for leafy vegetables. No differences were obtained in the rate of change of temperature in blanched and unblanched string beans, and she erroneously concluded that blanching does not permit closer packing of this product.

Thompson (13) in 1919 published a preliminary report upon a large amount of valuable work dealing with temperature-time relations in various fruits and vegetables during processing, in which he made use of thermocouples. From these tests he developed mathematical formulas the object of which was to make possible the calculation of the temperature at the center of the can at any time during the processing, starting at any initial temperature.

Such formulas would be of great value if they could be made applicable to the handling of all food substances canned. In using such formulas, however, it is necessary to assume that all heat transferred is by conduction or else that any convection is very local. This would make the method inapplicable, apparently, for determining temperature changes in cans of substances such as string beans and peas, in which there is free convection, and would limit its usefulness to the canning of substances of heavy consistency, such as corn and squash. Inasmuch as the use of these formulas depends upon a constant factor, k (which in itself varies with different methods of processing, different containers, different kinds of food materials, differences in packs, and in some cases differences in varieties, stages of maturity, and other factors), it would seem that the establishment of the necessary constants would be very difficult and would in itself necessitate determinations which would give directly the original time-temperature facts desired. Furthermore, in certain substances the heat is carried inward during the first part of the processing period by convection, and in the latter part almost entirely by conduction. In other cases there is a change in the material in the can during processing resulting in the reverse of this, the heat passing

in at first by conduction and later by convection. Any formulas which take into consideration such factors as these must be very complex, indeed, and their application would be difficult and of doubtful value. This investigator may be able to overcome some of these difficulties in further work.

METHODS AND APPARATUS.

As has been pointed out, the earlier work upon the time-temperature relations in foods during canning made use of maximum thermometers, which were sealed into the material in the cans. While the information obtained in this way is valuable so far as it goes, for practical purposes and for the carrying out of careful scientific investigations the use of the maximum thermometer is out of the question. In the first place, for one experiment, which may require from one to many hours to complete, only one temperature reading can be obtained. In an experiment of this sort nothing is known of the exact length of time required for the material at the center of the can to reach the recorded temperature or of the length of time the temperature may have remained at that point. Furthermore, it is necessary to carry out many tests in order to record even a partial story of the time-temperature relations in a single can of material. To make studies of this kind of the most value, it is important to know not only what is the highest point reached, but also something of the rate of rise in temperature before that point is reached, and especially for how long it remains at or above the pasteurizing or sterilizing temperature during the processing.

To overcome the disadvantages of the maximum thermometer, thermocouples have been used in more recent investigations. These enable the worker to record the entire story of the temperature changes in any part of the can if desired, and when properly standardized they are highly accurate. The principal drawback in their use is the complexity of the equipment, which requires considerable technical skill to operate properly and the fact that the equipment is not available for many who would care to carry on studies in this field. Furthermore, thermocouples must be confined primarily to laboratory investigations, as they are unsuited to practical routine work.

With these facts in mind an endeavor was made to devise an apparatus which would be inexpensive to install, simple and easy to use, and at the same time sufficiently accurate for the determination of temperature changes under various conditions of processing. A standard method of determining temperature is by the use of the mercury thermometer, and it should be acceptable for this work, provided it is suitably constructed, properly calibrated, held securely,

and so placed as to make direct reading possible at all times during the processing. It is recognized, of course, that the mercury thermometer is subject to small inaccuracies, but when it is properly constructed and standardized these are too small to be of practical importance in work of this sort. In the work here reported special long-stemmed thermometers were employed which were calibrated for 6-inch immersion and graduated to read from -10° to $+150^{\circ}$ on the centigrade scale. When tested these thermometers showed a lag of only 15 seconds in passing from 0° to 100° —a lag even less than that of the thermocouple used by Thompson (13).

The use of long-stemmed thermometers for time-temperature studies is, of course, not new. Bitting (2) and others have employed them for experiments made when processing in the water and chlorid baths, but their use for tests carried on heretofore in the steam retort has not been found feasible. The difficulties have been successfully overcome, and the apparatus here described and illustrated shows how the temperature at the center of the can may be determined at all times, whether the processing is being done in the water bath or in the steam retort.

THE STEAM RETORT.

The steam retort used in these experiments was constructed from a piece of 8-inch water pipe 14 inches long, fitted at one end with a blind flange, which serves as the base of the retort, and at the other with a removable blind-flange cover. By means of $\frac{3}{4}$ -inch wrought-iron handles and hinged clamp bolts the cover may be placed in position and securely clamped down in a very few seconds. Steam from a boiler large enough to furnish an ample supply of steam at any pressure desired enters by way of a $\frac{1}{2}$ -inch pipe inserted in the side of the retort a few inches above the base, and an exhaust of the same size is provided in the bottom. A carefully tested and standardized pressure gauge is also attached.

In the cover a pet cock allows the rapid expulsion of air from the retort and also makes possible a continuous flow of steam about the test can during the processing. A 1-inch hole at the center of the cover is threaded to receive a special brass fitting to which the test can is attached. By means of a suitable gasket the joint is made steam tight, and with the brass fitting and the can in place the apparatus is ready for the insertion of the thermometer. The thermometer is passed through the brass fitting by way of a $\frac{3}{8}$ -inch hole until the bulb reaches the center of the test can, as determined by careful measuring beforehand, the funnel-shaped depression in the stem of the fitting provided with a suitable gasket, and the cap screwed down. The thermometer is thus held securely in position, and a steam-tight closure is easily made.

It will be seen, therefore, that the test can is firmly attached to the cover of the retort by means of the brass fitting, and the can may be placed in or removed from the retort in a very few seconds by simply putting on or taking off the cover. Owing to the small size of the retort, equilibrium at any steam pressure desired may be attained in

10 to 30 seconds.

The top of the mercury column is always in sight, and the temperature at the center of the container may be read directly at any time. Figure 1 shows the arrangement of the apparatus and the position of the test can in the retort.

THE BRASS FITTING.

The accompanying illustrations (fig. 2) show in detail the structure of the special fitting to which the can is attached for the test. Numerous modifications of this are possible, to suit all needs. The original form is shown at A. The threaded stem screws into the cover of the retort until the hexagonal shoulder presses upon the gasket and forms a

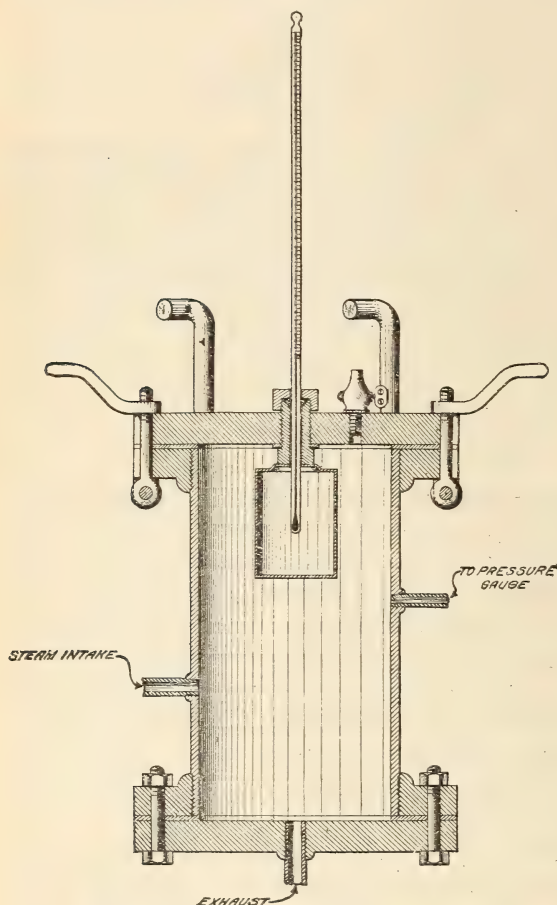


FIG. 1.—Apparatus designed for making time-temperature tests in canning food products, showing the position of the test can in the retort and the arrangement of the long-stemmed thermometer used in taking can temperatures.

steam-tight joint with the retort cover. The threaded portion below the shoulder screws into the hole of the ordinary maximum thermometer test can in common use. With suitable gaskets air-tight joints are made, and the can may be attached or removed as desired. Cans of this type were used largely in these investigations. The $\frac{3}{8}$ -inch hole through which the thermometer is passed is reamed out

at the upper end to form a funnel-shaped depression to allow suitable packing, and the cap screws down to hold this tightly about the thermometer and make the seal perfect. In practice, this fitting is rarely removed from the retort cover, the can being unscrewed from beneath and the thermometer removed by unscrewing the cap.

It will be seen that this apparatus is as well suited for use with thermocouples as with thermometers.

A modification of *A* is shown at *B*, differing from it in that the fitting may be soldered directly to an ordinary hole-and-cap can.

For work with glass jars, those of the Mason screw-top type were used. These were attached to the fitting *A* (fig. 2) by removing the

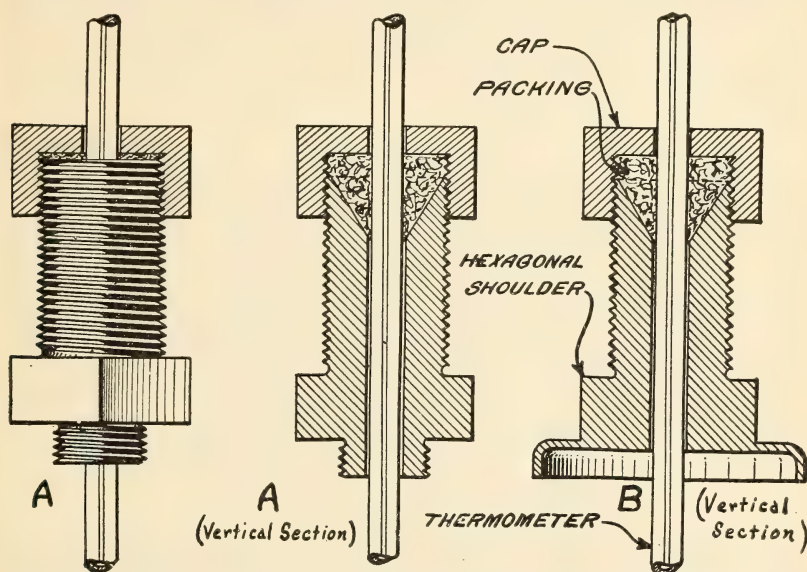


FIG. 2.—Details of the special fitting to which the can is attached for the test: *A*, The original form; *B*, a modification of *A*, differing from it in that the fitting may be soldered directly to an ordinary hole-and-cap can.

porcelain in the top, cutting a hole in the metal large enough to receive the portion of the fitting below the shoulder, and securing it firmly to the fitting by means of a suitable gasket and nut. The jar could then be placed in position for the test by simply screwing it into the top.

This apparatus as described may be constructed in any well-equipped machine shop at small expense. It is easy to operate, requires no special training for carrying out the tests beyond that possessed by anyone familiar with canning operations, and is sufficiently accurate for all practical needs. Tests made by its use have been carefully checked with thermocouples, and the differences observed in the results have been too small to be of practical significance. Any-

one, therefore, desiring to undertake time-temperature studies with canned foods need not hesitate to make use of this or a similar device.

THEMOCOUPLES.

The thermocouples used were constructed of copper and constantan wires by Dr. R. B. Harvey, of the Office of Plant Physiological and Fermentation Investigations, to whom the writers are greatly indebted for assistance in installing and standardizing the thermo-electrical equipment. The constant junction was located in an ice bath maintained at 0° C. by means of a thermos bottle filled with an ice and water mixture, and the variable junction was placed in the center of the container of material under test. The potential was measured with a potentiometer of recognized standard and a reflection type of galvanometer.

THE WATER BATH.

In all time-temperature experiments conducted at 100° C., a water bath was used. This consisted of a wooden tank 18 by 18 by 30 inches lined with galvanized iron and heated by means of a steam coil constructed from $\frac{3}{4}$ -inch pipe. The water was maintained at a constant level and kept vigorously boiling throughout the tests. Owing to the large volume of water in the bath, there was no cessation of boiling when the cans and jars were introduced. The temperature was therefore always 100° C., a condition which often does not obtain when small kettles or pots are used for the purpose.

PRELIMINARY EXPERIMENTS.

To obtain a thorough understanding of the factors influencing temperature changes in the can during the processing period and the subsequent cooling it was considered advisable to make some preliminary experiments which would serve as a basis for comparison. In these experiments distilled water, brines of various concentrations, and solutions of sugar and starch were treated as here described. The processing was done in the water bath at 100° C., and in the case of distilled water also in the retort at 109°, 116°, and 121° C.

DISTILLED WATER.

The first of these experiments was carried out with distilled water, using No. 2, No. 3, and No. 10 tin cans and pint and quart glass jars. In the case of the tin cans the water was filled to within one-fourth of an inch of the top and the device for holding the thermometer soldered to the can, making a steam-tight joint. In the glass a steam-

tight closure could not be made, owing to the inability of the glass to stand steam pressure.

Figure 3 shows the curves representing the temperature changes during the processing period and also the cooling in air and in water. These represent the averages of six tests for the rise in temperature during processing, but the cooling in water and in air are the averages of only three tests. The temperatures of the air and of the water in the different cooling tests varied somewhat, so that the curves are not absolutely uniform. The initial temperature was 20° C. The temperature of the water in which the cooling was done varied between 15° and 18° C. It is seen that the change in temperature at the center of the can is exceedingly rapid when the can

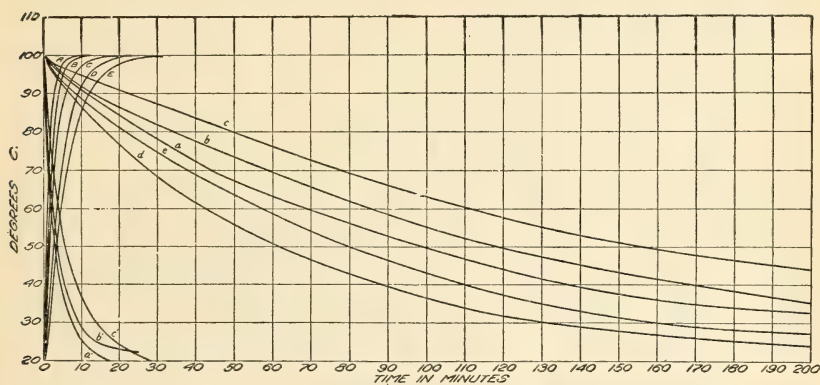


FIG. 3.—Time-temperature relations for distilled water when processed in various containers at 100° C. The curves representing rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of 30 seconds; curves representing cooling in air, from readings at intervals of 5 to 10 minutes. Rise in temperature: A, In No. 2 tin cans; B, in No. 3 tin cans; C, in No. 10 tin cans; D, in pint glass jars; E, in quart jars. Cans cooled in water: a', No. 2 at 17° C.; b', No. 3 at 16° C.; c', No. 10 at 16½° C. Cooled in air: a, No. 2 cans at 17° to 20° C.; b, No. 3 cans at 16° to 20° C.; c, No. 10 cans at 16° 18° C.; d, pint glass jars at 16° to 18° C.; e, quart glass jars at 18° to 20° C.

is plunged into the water bath at 100° C. In the No. 2 tin can the temperature of the bath is approached in about eight minutes. It is also noted that the No. 3 can is only slightly slower than the No. 2, requiring only two or three minutes longer to attain the temperature of the bath. The No. 10 tin can is somewhat slower than the No. 3, but even here the temperature at the center approaches that of the retort in 15 minutes. The temperature changes in the glass containers are very much slower than in the tin, requiring about 20 minutes for the temperature of the center of the pint jar to approach that of the water bath, and about 27 minutes for the quart jar to reach the same temperature. There is thus a very marked retardation in the glass. When the tin containers are removed from the boiling water bath and placed in water at 17° C. there is a very

sudden drop in the temperature at the center of the can. It falls to 30° in a very few minutes, the rate of cooling being only slightly slower than the rate of rise in temperature. As will be seen, the cooling in air is very slow when contrasted with the cooling in water. No cooling tests of glass in water, of course, could be made. In these tests in the cooling in air the glass cooled considerably faster than the tin. The diameter of the No. 2 tin can is less than that of the quart glass jar, yet the quart jar cools faster. This may have been caused in part by leakage around the cover of the jar, since a steam-tight closure was not possible, but it must be due largely to

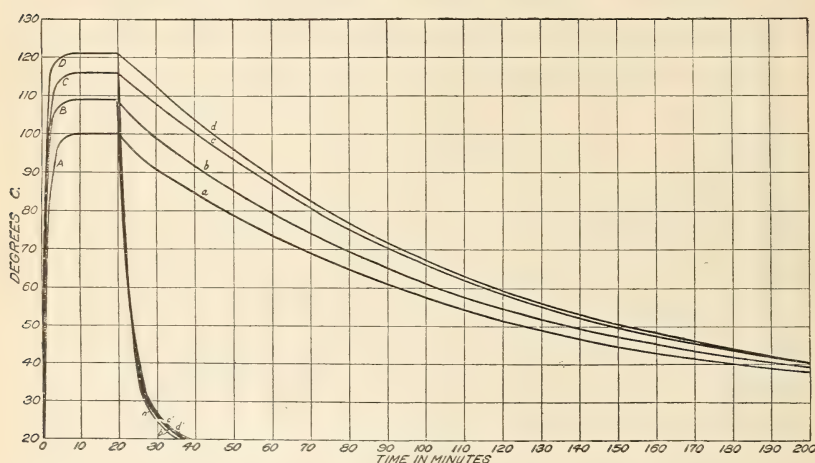


FIG. 4.—Time-temperature relations for distilled water when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in air and in water. The curves representing the rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of 30 seconds; curves representing cooling in air, from readings made at intervals of 5 to 10 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall when cooled: *a'*, From 100° C. in water at 17° C.; *b'*, from 109° C. in water at 15° C.; *c'*, from 116° C. in water at 16° C.; *d'*, from 121° C. in water at 16° C.; *a*, from 100° C. in air at 17° to 20° C.; *b*, from 109° C. in air at 20° to 24° C.; *c*, from 116° C. in air at 25° C.; *d*, from 121° C. in air at 25° C.

the fact that glass radiates heat faster than tin. The rate of cooling in tin is in the order of the diameter of the cans, the No. 10 being slowest, the No. 3 next, and the No. 2 fastest. The pint glass jar is faster than the quart glass jar or the No. 2 tin can. The temperature of the room was not constant, varying between 16° and 20° C. The length of time necessary for any container to reach any specific temperature is shown by the curves.

In figures 4 to 7 are shown the curves representing the temperature changes at the center of the various cans of distilled water when processed at 100°, 109°, 116°, and 121° C. Since a steam-tight closure could not be made in the glass, any temperature above 100°

fell to 100° C. as rapidly as the temperature of the retort was lowered. The temperature at the center of the glass container was thus

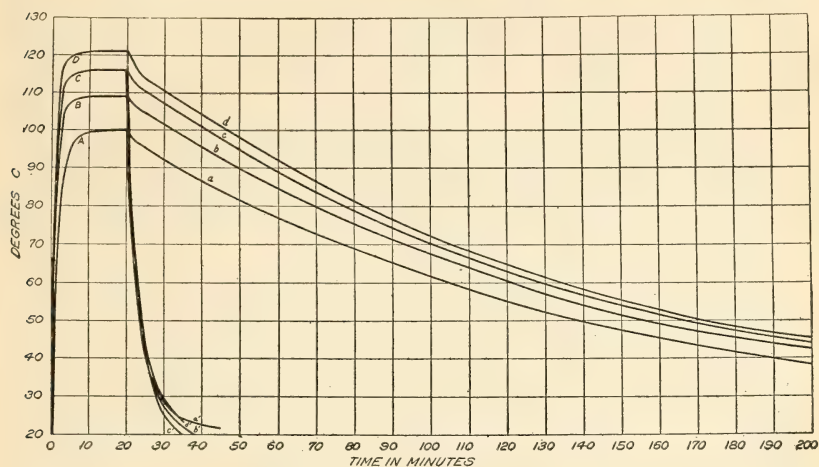


FIG. 5.—Time-temperature relations for distilled water when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in water and in air. The curves representing the rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of 30 seconds; curves representing cooling in air, from readings at intervals of 5 to 10 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall when cooled: a', From 100° C. in water at 16° C.; b', from 109° C. in water at 17° C.; c', from 116° C. in water at 15° C.; d', from 121° C. in water at 17° C.; a, from 100° C. in air at 16° C.; b, from 109° C. in air at 25° C.; c, from 116° C. in air at 25° C.; d, from 121° C. in air at 25° C.

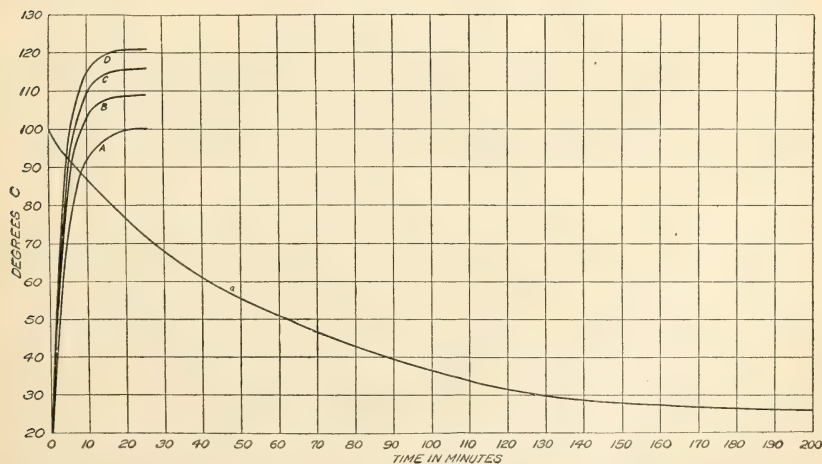


FIG. 6.—Time-temperature relations for distilled water when processed in pint glass jars at 100°, 109°, 116°, and 121° C. and also when cooled in air. The curves representing the rise in temperature during processing were plotted from readings made at intervals of 30 seconds; the curve representing cooling in air, from readings at intervals of 5 to 15 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. a, Fall from 100° C. when cooled in air at 15° to 20° C.

always at 100° C. when taken from the retort, and the cooling curve from this starting point is all that is given. In the case of the tin

cans processed at temperatures above 100° and cooled in air the sudden drop in temperature to 100° C. is not noted, the temperature falling gradually, and still more slowly as it approaches that of the room. These differences in cooling between the tin and glass containers are to be observed throughout the whole series of experiments.

One fact of importance shown by the curves is that the length of time required for the center of any can to attain the temperature of the bath or retort is approximately the same for all the temperatures here used, except that in some tests the boiling-water bath required a slightly longer time.

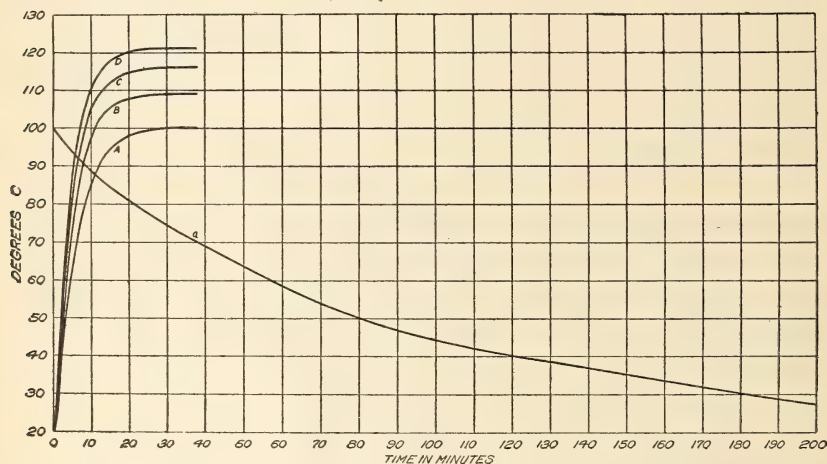


FIG. 7.—Time-temperature relations for distilled water when processed in quart glass jars at 100° , 109° , 116° , and 121° C. and also when cooled in air. The curves representing the rise in temperature during processing were plotted from readings made at intervals of 30 seconds; the curve representing cooling in air, from readings at intervals of 5 to 15 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. a, Fall from 100° C. when cooled in air at 18° to 20° C.

BRINE.

To determine whether the addition of salt would have any direct influence upon the rate of change in temperature in the can, comparative tests were made, using distilled water, a 2 per cent brine, and a saturated brine. In figure 8 curves for saturated brine and distilled water show that the difference between distilled water and a saturated brine is insignificant. From the results of these experiments it is concluded that the proportion of salt commonly added to canned materials has no direct effect upon the rate of change of temperature at the center of the can.

SUGAR SOLUTIONS.

In order to get an idea of the possible effect that the addition of sugar to canned materials has upon the rate of change of temperature

in the can, comparative tests were made with 10 per cent, 30 per cent, and 60 per cent cane-sugar solutions. This series of tests was made with No. 3 tin cans in the boiling-water bath as the heating medium, and in circulating water at 17°C . as the medium for cooling. In each of the tests the cans were filled with the solution to within one-fourth of an inch of the top. The device for holding the thermometer was soldered in place and the thermometer so placed that the bulb was at the center of the can. The curves in figure 9 show the results obtained. The sugar solutions show no marked effect upon the rate of changes of temperature at the center of the can, where the concentration is 10 per cent or less. Even in a 60 per cent

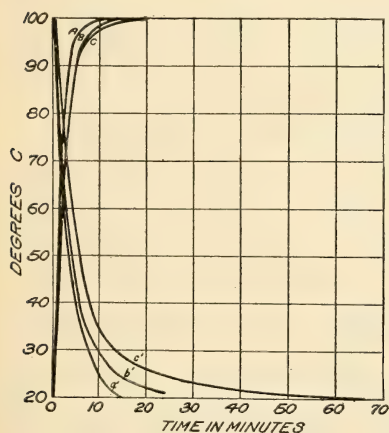


FIG. 9.—Time-temperature relations for 10 per cent, 30 per cent, and 60 per cent cane-sugar sirup when processed in No. 3 tin cans at 100°C . and also when cooled in water. These curves were plotted from temperature readings made at intervals of 1 minute. Rise in temperature: A, For 10 per cent sirup; B, for 30 per cent sirup; C, for 60 per cent sirup. Fall in temperature from 100°C when cooled: a' , For 10 per cent sirup in water at $12\frac{1}{2}^{\circ}\text{C}$.; b' , for 30 per cent sirup in water at 17°C .; c' , for 60 per cent sirup in water at $15\frac{1}{2}^{\circ}\text{C}$.

of the can approaches that of the bath. It is known that the viscosity of the sugar solutions decreases as the temperature increases. It is this characteristic of sugar solutions that makes the temperature shown by the upward curves follow so closely that of distilled water.

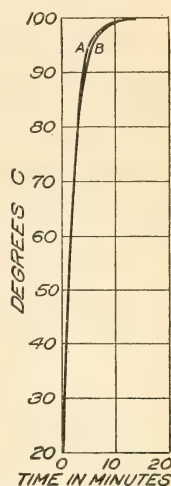


FIG. 8.—Time-temperature relations for distilled water and saturated brine when processed in No. 3 tin cans at 100°C . These curves were plotted from temperature readings made at intervals of 1 minute. A, Distilled water; B, saturated brine.

solution of sugar the effect is less marked than might be expected. The effect of the sugar solution upon the rate of change of temperature at the center of the can is due to the greater viscosity, which decreases

the rate of convection in the sugar solutions. The value of the force which tends to produce convection currents in the solution depends upon the steepness of the gradient between the temperature at the center of the can and the temperature at the margin of the solution, so that the force tending to produce convection currents becomes less and less as the temperature at the center

In the cooling off, however, there is an increase in the viscosity as the temperature falls. Also, as the temperature at the center of the can falls the temperature gradient between the center and the margin becomes flatter; hence, the force tending to cause convection becomes smaller and smaller, until finally the resistance due to viscosity is great enough to stop all convection, and the process becomes one of pure conduction, which is very much slower than convection. A pronounced flattening of the curve for 60 per cent sirup at about 30° C. is significant. The difference in viscosity at high and low temperatures makes the cooling curve much different from the upward curve. It appears from other tests that sugar solutions of 1 to 4 per cent when added to materials which are canned have very little effect upon the temperature change in the can, but concentration as high as 30 to 60 per cent will have considerable effect.

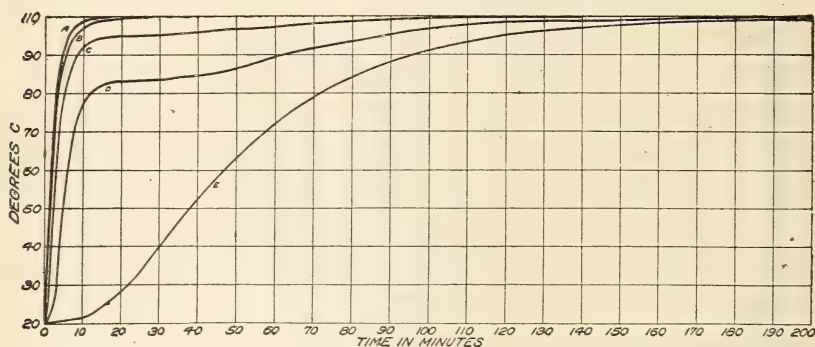


FIG. 10.—Time-temperature relations for 1 per cent, 2 per cent, 3 per cent, 4 per cent, and 5 per cent starch solutions when processed in No. 3 tin cans at 100° C. Curves A to D were plotted from temperature readings made at intervals of 1 minute and curve E from readings at intervals of 5 minutes. Rise in temperature: A, For 1 per cent solution; B, for 2 per cent solution; C, for 3 per cent solution; D, for 4 per cent solution; E, for 5 per cent solution.

STARCH SOLUTIONS.

To study further the effect of viscosity upon the rate of change of temperature in the can 1, 2, 3, 4, and 5 per cent starch solutions were tested in No. 3 tin cans in the boiling-water bath. No cooling tests were made. Carefully dried starch was weighed out and enough water added to make 1, 2, 3, 4, and 5 per cent solutions, respectively. The starch was gelatinized or brought into colloidal solution by heating on a steam bath for one hour, with constant stirring, and at the end of this time enough water was added to each lot to equal that lost by evaporation. Each lot appeared as a homogeneous grayish semi-transparent solution or paste. The lots were then cooled to 20° C., put into cans, and the thermometer-holding device soldered to the cans, as described under "Distilled water." Figure 10 shows the curves for these tests. Each curve represents the average of three tests.

It is seen from the curves that the rate of change of temperature at the center of the can in 1 per cent and 2 per cent starch solutions is not very different from that in distilled water, although there is a slight slowing down of the process. Curve *C*, figure 10, shows that the first part of the process of the 3 per cent solution is very rapid, but when the center of the can reaches about 92° C. there is a very marked slowing down of the rate of rise of temperature. Also in curve *D*, representing the 4 per cent starch solution, the first part of the process is very rapid, but when the temperature at the center of the can reaches about 80° C. there is a marked slowing down of its rate of rise. It stops almost entirely at about 83° and remains there for 10 to 15 minutes; then it begins to rise again, and gradually approaches the temperature of the bath. In the 5 per cent solution the process is slow from the beginning. It is clear that in the 1 per cent and 2 per cent solutions and in the first part of the processes of the 3 per cent and 4 per cent solutions convection is occurring, which explains the rapid rise in temperature at the center of the can. In the 5 per cent starch solution and in the last part of the process of the 3 per cent and 4 per cent solutions convection is not occurring to any great extent, and the heat reaches the center of the can by conduction only. In the 4 per cent solution the resistance due to the viscosity is not great enough to stop convection in the first part of the process. The force tending to produce convection becomes less and less as the temperature at the center of the solution approaches the temperature of the bath. Hence, convection continues in the solution until this force becomes so small that it fails to overcome the resistance due to viscosity, when the process of convection stops. Then the heat is conveyed only by conduction. This is probably what happened in the 3 per cent and 4 per cent starch solutions. Further change in the starch may have been a factor, as no tests were made to determine whether the starch solution had reached its maximum viscosity in the preliminary treatment. The curves for cooling in water would have been interesting, but unfortunately they were not made.

From these preliminary experiments it is concluded that the factors affecting the rate of change of temperature at the center of the can are the diameter of the container, the conductivity, thickness and radiative power of its walls, the temperature, conductivity, and mobility of its contents, and the temperature, conductivity, and movement of the medium surrounding it.

SINGLE-PERIOD PROCESSING.

With the facts of the preliminary experiments in mind, work was done with the various fruits and vegetables commonly canned, for

the purpose of determining to what extent these factors are of importance in actual canning practice. No attempt to follow exactly the procedure of any specific canning method was made, the object being to get at the underlying principles and fundamental factors of the time-temperature relations rather than to check up on prevailing methods.

STRING BEANS.

In the tests with string beans the Green Pod Stringless variety was used. The beans were gathered from the field, brought into the laboratory, washed, broken into pieces 1 to $1\frac{1}{2}$ inches long, and then

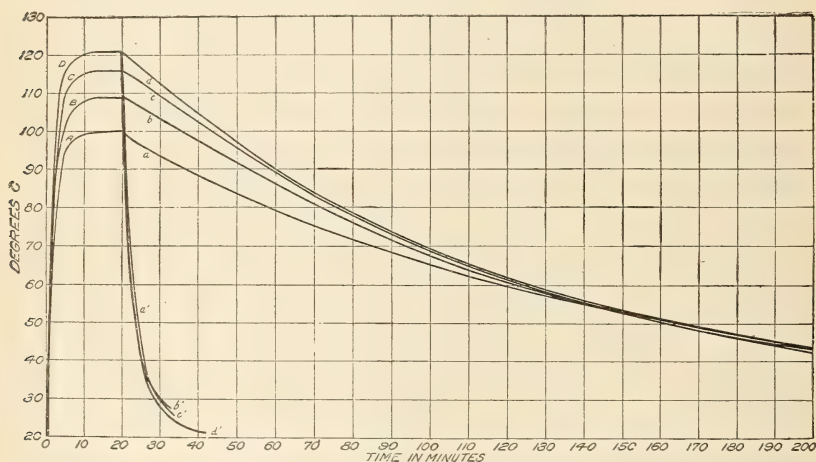


FIG. 11.—Time-temperature relations for string beans in 2 per cent brine when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in air and in water. The curves representing the rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of $\frac{1}{2}$ minute and 1 minute; those representing cooling in air, from readings at intervals of 5 to 10 minutes. Rise in temperature when processed: *A*, At 100° C.; *B*, at 109° C.; *C*, at 116° C.; *D*, at 121° C. Fall in temperature when cooled: *a'*, From 100° in water at 17° C.; *b'*, from 109° in water at 17° C.; *c'*, from 116° in water at 16½° C.; *d'*, from 121° in water at 16½° C.; *a*, from 100° in air at 16° to 20° C.; *b*, from 109° in air at 19° to 22° C.; *c*, from 116° in air at 18° to 22° C.; *d*, from 121° in air at 19° to 22° C.

blanched for five minutes in boiling water. They were then allowed to cool to room temperature and placed in the cans. Two per cent brine was added to fill the interspaces. They were then processed at 100°, 109°, 116°, and 121° C. in No. 2 and No. 3 tin cans and in pint and quart glass jars. Figures 11 to 14 show the rise in temperature at the center of the various containers at the different processing temperatures.

It is observed that the rise of temperature is almost as rapid as that of distilled water alone. In 12 to 13 minutes the temperature at the center of the No. 2 tin can approaches or attains that of the retort or bath, and in 15 to 16 minutes the temperature of the No. 3 can

approaches that of the retort or bath. It requires about 30 minutes for the pint glass jar and about 35 minutes for the quart jar to reach

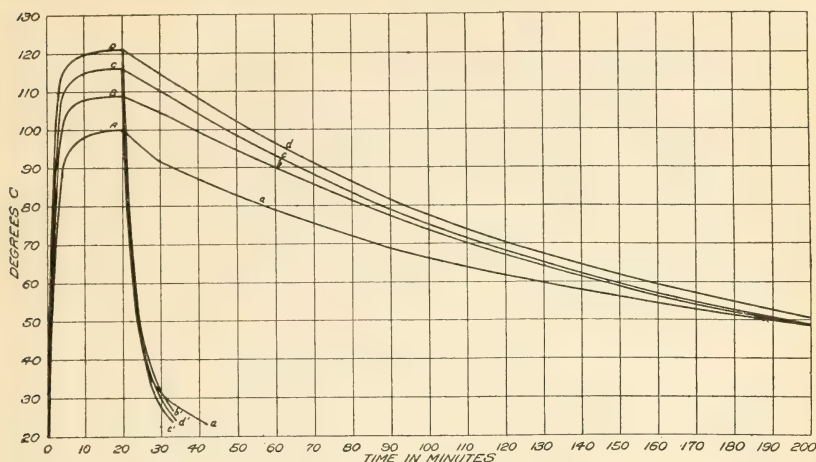


FIG. 12.—Time-temperature relations for string beans in 2 per cent brine when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in water and in air. The curves representing the rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of $\frac{1}{2}$ minute and 1 minute; those representing fall in temperature during cooling in air, from readings at intervals of 5 to 10 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall in temperature when cooled: *a'*, From 100° in water at 17° C.; *b'*, from 109° in water at 16½° C.; *c'*, from 116° in water at 16½° C.; *d'*, from 121° in water at 16½° C.; *a*, from 100° in air at 25½° C.; *b*, from 109° in air at 25½° C.; *c*, from 116° in air at 25½° C.; *d*, from 121° in air at 22° to 26° C.

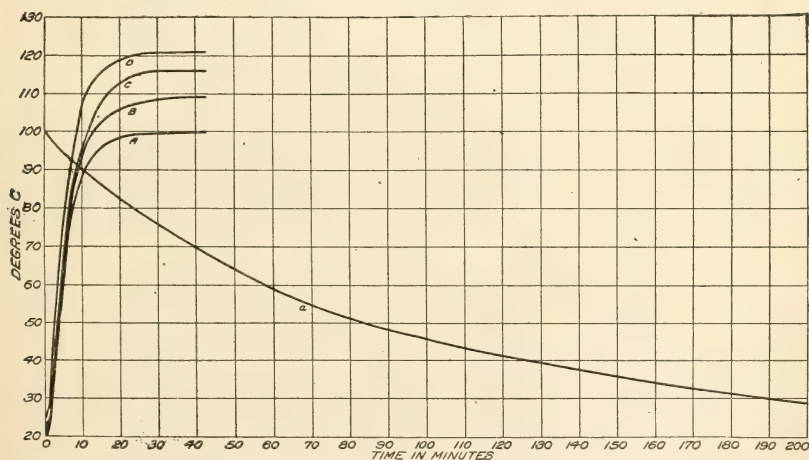


FIG. 13.—Time-temperature relations for string beans in 2 per cent brine when processed in pint glass jars at 100°, 109°, 116°, and 121° C. and also when cooled in air. The curves representing the rise in temperature during processing were plotted from readings made at intervals of 1 minute; the curve representing the cooling in air, from readings at intervals of 1 to 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. *a*, Fall in temperature from 100° when cooled in air at 18° to 22° C.

the same temperature. It is evident that so far as time-temperature relations in the can are concerned there need be little difference in

the time for the processing of No. 2 and No. 3 tin cans of string beans. A somewhat longer time obviously should be recommended for the glass containers.

The temperature of the retort or bath is approached in practically the same time whether the processing temperature is 100°, 109°, 116°, or 121° C. Furthermore, the rise in temperature is so prompt that the stirring of the material, as in an agitating cooker, would be of no advantage in distributing the heat throughout the can.

It is to be understood that the temperature here measured is that of the liquid surrounding the beans. No record was obtained of the actual temperature in the beans themselves, but it would take at most only a few minutes longer for the heat to reach the center of the beans.

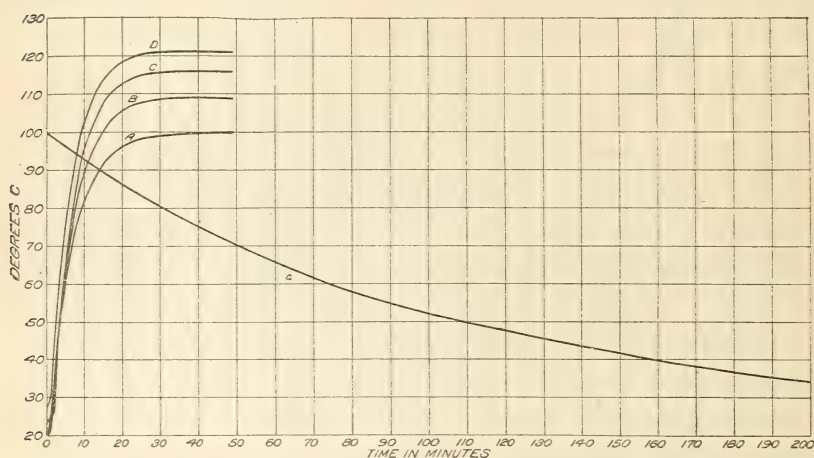


FIG. 14.—Time-temperature relations for string beans in 2 per cent brine when processed in quart glass jars at 100°, 109°, 116°, and 121° C. and also when cooled in air. The curves representing the rise in temperature during processing were plotted from readings made at intervals of 1 minute; the curve representing the cooling in air, from readings at intervals of 1 to 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. a, Fall in temperature when cooled in air at 18° to 22° C.

Records of the temperature for the cooling, both in air and in water, were obtained. They are very similar to the cooling of distilled water, but are somewhat slower. Here, again, the very great difference in the rate of cooling in air and in water should be emphasized. When the containers were cooled in water the temperature fell to 30° C. in 10 minutes or less, while it took more than 3 hours to fall to the same temperature in air. In the glass, where a steam-tight closure could not be made, any temperature above 100° C. fell to 100° as rapidly in the container as in the retort, so that the temperature of the glass containers was always 100° when removed from the retort.

The temperature changes obtained in these tests are easily understood when the composition of the beans and the character of the pack are held in mind. The string beans contain only a small proportion of starch or other colloidal material which would readily go into solution or gelatinize, so the free liquid in the can is thus maintained throughout the processing period. This medium allows of convection, which rapidly distributes the heat throughout the can.

The surface tension between the liquid and the insoluble particles of material tends to obstruct convection currents, but since the pieces of material in this case are comparatively large the effect of the force of surface tension is correspondingly small. However, if the material is finely divided, as when it is ground in a food chopper, the surface tension is increased to such an extent as to cut down very greatly the rate of change of temperature.

Experiments were also made to determine whether the fullness of the pack has any effect upon the rate of change of temperature in the center of the can. In cans packed extra full and in cans lightly packed the differences were found to be so small as to be almost negligible. However, when the beans are thoroughly cooked they may be packed in the can so tightly as to make the interspaces filled with liquid more or less discontinuous, in which case there is a very marked slowing down of the temperature changes at the center of the can.

PEAS.

The variety of garden peas used in these tests was the Early Alaska. The peas were gathered from the field as used and brought into the laboratory and shelled by hand. In some of the tests the peas had somewhat passed the prime stage for canning. No attempt was made to grade them. They were blanched five minutes in the boiling-water bath and cooled to room temperature. The tin cans were filled to within one-fourth of an inch, and the glass jars to within half an inch of the top. Then enough 2 per cent brine was added to cover the peas. Each kind of container was processed at 100°, 109°, 116°, and 121° C. They were each cooled in air, and the tin cans were also cooled in water. Figure 15 shows the time-temperature record of a No. 2 can during the processing period at the various temperatures and also the cooling in air and in water. Figures 16, 17, and 18 show the temperature curves for the processing period in the No. 3 tin can and in the pint and quart glass jars, respectively.

It is observed from these curves that the temperature rises very rapidly. The No. 2 tin can approaches the temperature of the retort, or bath, in about 12 minutes, the No. 3 can in about 15 minutes, the pint glass jar in 30 minutes, and the quart jar in about 35 minutes.

The temperature changes are like those in string beans except that the time required to pass through the last degree is in most cases very much longer in the peas than in the string beans. Some viscous colloidal material cooks out into the free liquid during the processing period. The liquid seems to reach such viscosity as to stop convection currents at this point. The viscosity does not have to be very great in order to stop convection when the difference in temperatures at the center of the can and at the margin is one degree or less.

The difference in cooling in air and water is very marked, as is shown by the curve in figure 15. The curves for cooling in water show a marked slowing down of the fall of temperature when it

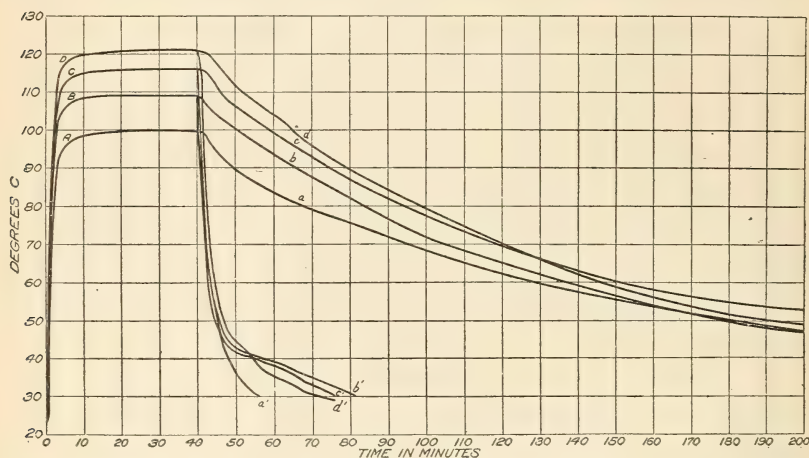


FIG. 15.—Time-temperature relations for peas in 2 per cent brine when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in water and in air. The curves representing the rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of $\frac{1}{2}$ minute and 1 minute; those for cooling in air, from readings at intervals of 5 to 10 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall in temperature when cooled: a', From 100° in water at 20° C.; b', from 109° in water at 17° C.; c', from 116° in water at 20° C.; d', from 121° in water at 19° C.; a, from 100° in air at 26° to 30° C.; b, from 109° in air at 24° to 28° C.; c, from 116° in air at 24° to 28° C.; d, from 121° in air at 24° to 28° C.

reaches about 45° C., in those curves cooling from 121°, 116°, and 109° C. The one processed at 100° does not follow the same course as the other three. During the processing at the higher temperatures some soluble colloidal material was cooked out, which formed a solution so viscous as to stop convection at this point in the cooling. This does not occur in every case, and the rather mature condition of the samples used in these cases perhaps explains its occurrence here.

As in string beans, there need be little difference in the length of the processing period for No. 2 and No. 3 tin cans, as far as the rate of change of temperature at the center is concerned. The time for the processing of glass jars, however, should be longer.

Stirring the material during processing is of no advantage, because there is no difficulty in getting the heat to the center of the can.

It must be remembered also that the cooling is much faster in air than in the retort. If the cans are left packed in the retort to cool, the temperature may remain above 100° C. for 1 hour or longer. If the processing has been sufficient, a rapid cooling is of advantage,

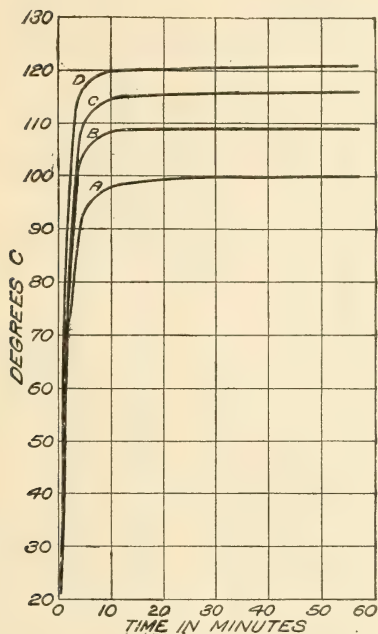


FIG. 16.—Time-temperature relations for peas in 2 per cent brine when processed in No. 3 tin cans at 100° , 109° , 116° , and 121° C. These curves were plotted from temperature readings at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

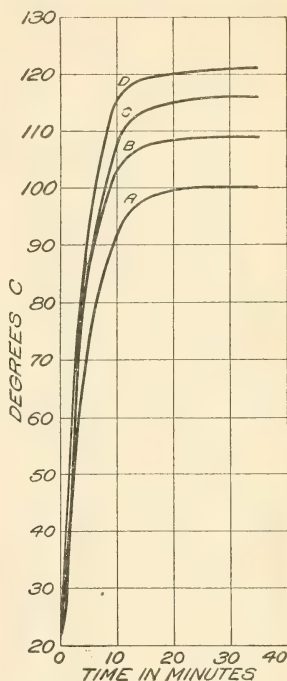


FIG. 17.—Time-temperature relations for peas in 2 per cent brine when processed in pint glass jars at 100° , 109° , 116° , and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

because the high temperature continues to alter the flavor and quality of the product.

Here, again, the temperature records shown are for the liquid filling the spaces between the peas, no attempt being made to measure the temperature within the peas themselves. This could have been done with suitable thermocouples, but it could not take more than a very few minutes for the heat to be conducted from the surrounding

liquid to the center of the peas. If the peas are fresh and sound the organisms to be destroyed would be on the surface and not in the center of the peas.

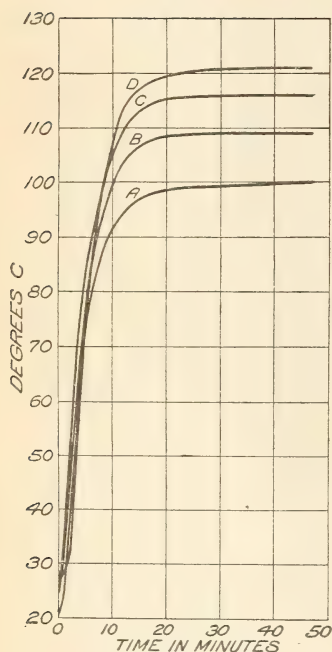


FIG. 18.—Time-temperature relations for peas in 2 per cent brine when processed in quart glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

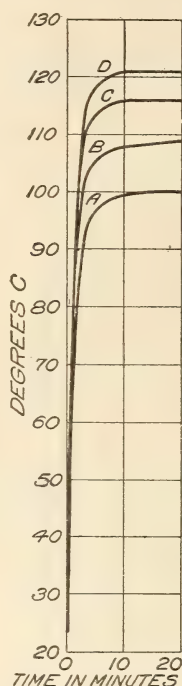


FIG. 19.—Time-temperature relations for Lima beans in 2 per cent brine when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

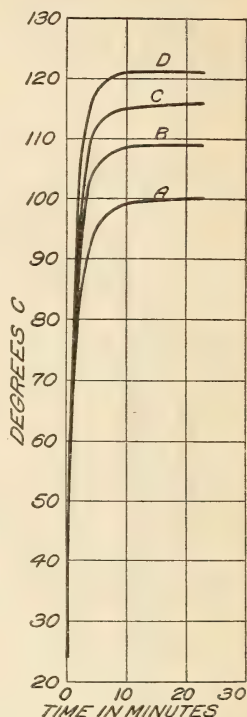


FIG. 20.—Time-temperature relations for Lima beans in 2 per cent brine when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

LIMA BEANS.

The variety of Lima beans used in these tests was the Dwarf Garden King. The beans were full grown but not dry and were in prime condition for table use. They were gathered, brought into the laboratory, and shelled by hand. The shelled beans were washed and packed tightly into the cans without being blanched, and only enough

2 per cent brine added to cover the beans. They were processed in the same way as the string beans. The results are shown in figures 19 to 22.

It will be seen from these curves that the rate of temperature change in Lima beans does not differ essentially from that in string beans. The stirring of the material during processing is unnecessary. Cooling tests in water were not made, and the curves for cooling in

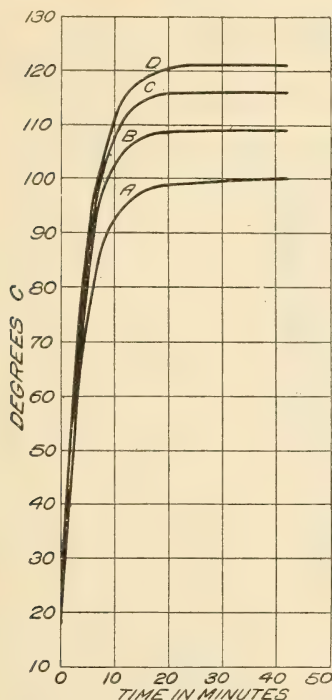


FIG. 21. — Time-temperature relations for Lima beans in 2 per cent brine when processed in pint glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

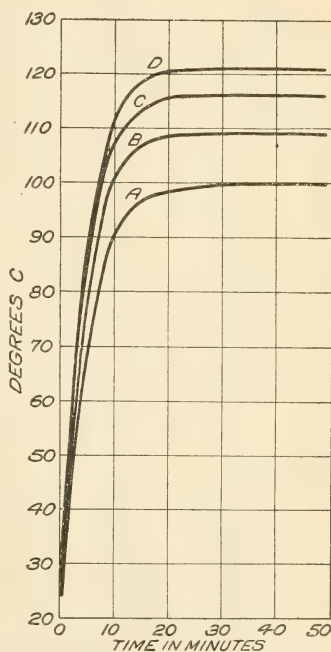


FIG. 22. — Time-temperature relations for Lima beans in 2 per cent brine when processed in quart glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

air, which were found to be very similar to those for string beans, are omitted, as they add nothing of value.

SOY BEANS.

The variety of soy beans used in these tests was the Easy Cook. The beans were gathered when most of the pods were beginning to turn yellow. They were brought into the laboratory, spread upon

trays, and steamed for 5 minutes to soften the hulls so that the shelling could be done more readily. The shelled beans were filled into the cans and enough 3 per cent brine was added to cover the beans. The usual tests in No. 2 and No. 3 tin cans and pint and quart glass jars at 100°, 109°, and 121° C. were carried out. No cooling in water was made. Figures 23 to 26 show the rise in temperature at the center of the cans for both tin and glass containers.

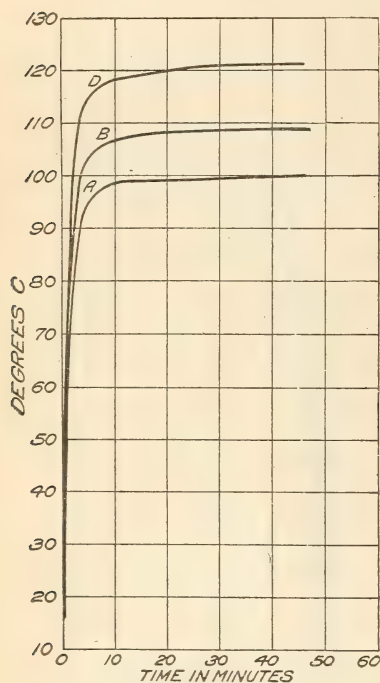


FIG. 23.—Time-temperature relations for soy beans (Easy Cook) in 3 per cent brine when processed in No. 2 tin cans at 100°, 109°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; D, at 121° C.

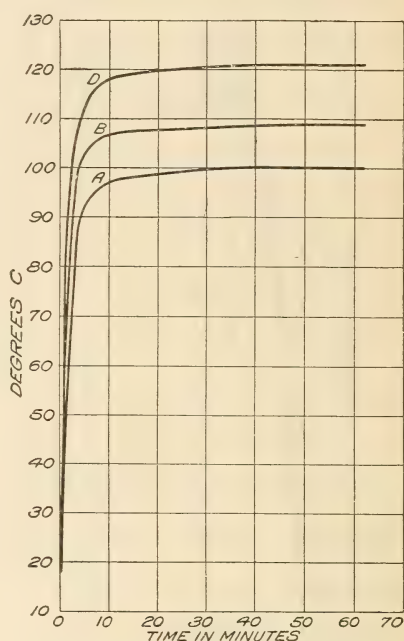


FIG. 24.—Time-temperature relations for soy beans (Easy Cook) in 3 per cent brine when processed in No. 3 tin cans at 100°, 109°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; D, at 121° C.

The temperature rises very rapidly during the first part of the processing period. When it approaches to within 2 or 3 degrees of that of the retort, or bath, the rise in temperature is much slower than in the string beans. The soy beans contain a very soluble protein which quickly cooks out into the surrounding liquid, the viscosity of which soon becomes such as to stop all convection currents. The heat then passes inward by conduction, which is comparatively slow. The cooling in air is considerably slower than in string beans or peas. No cooling in water was made, but it would

very probably have been much slower than for string beans, for the cooking out of viscous colloidal substances greatly affects the rate of cooling.

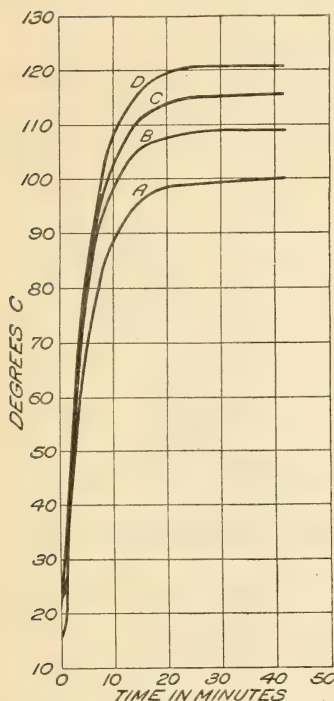


FIG. 25.—Time-temperature relations for soy beans (Easy Cook) in 3 per cent brine when processed in pint glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

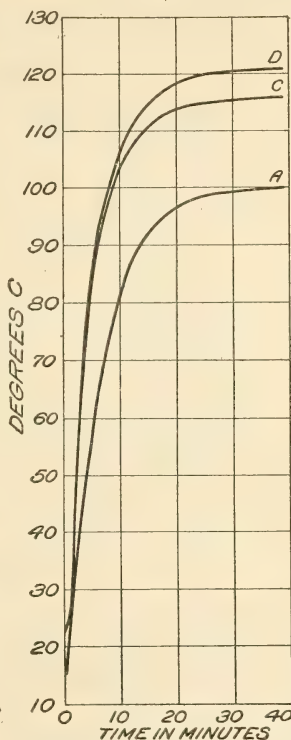


FIG. 26.—Time-temperature relations for soy beans (Easy Cook) in 3 per cent brine when processed in quart glass jars at 100°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; C, at 116° C.; D, at 121° C.

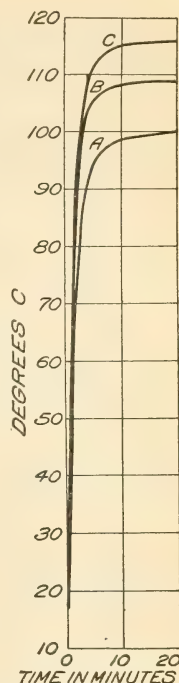


FIG. 27.—Time-temperature relations for asparagus in 2 per cent brine when processed in No. 2 tin cans at 100°, 109°, and 116° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.

The differences in No. 2 and No. 3 tin cans and pint and quart glass jars are the same as noted in string beans, and the same conclusions can be drawn as to the length of time for processing.

Experiments have shown that the readiness with which viscous materials cook out in soy beans varies considerably in the different varieties and with the different stages of maturity. Of the several varieties tested the Easy Cook is the softest and the cooking out is

greatest. Also the amount of soluble protein material which cooks out in processing seems to increase as the beans approach a mature or ripe stage.

ASPARAGUS.

Rather comprehensive studies were made with asparagus, which included experiments to show the effect of differences in the nature of

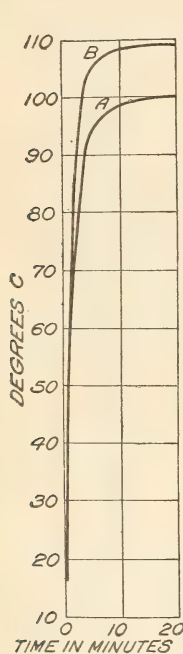


FIG. 28.—Time-temperature relations for asparagus in 2 per cent brine when processed in No. 3 tin cans at 100° and 109° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, at 100° C.; B, at 109° C.

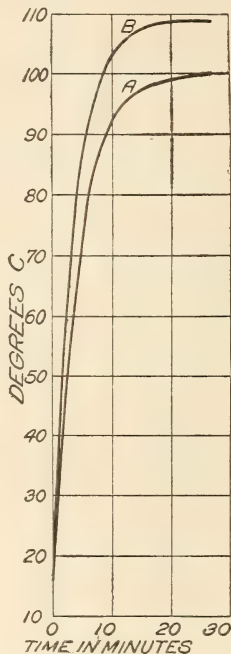


FIG. 29.—Time-temperature relations for asparagus in 2 per cent brine when processed in pint glass jars at 100° and 109° C. These curves were plotted from temperature readings made at intervals of $\frac{1}{2}$ minute and 1 minute. Rise in temperature when processed: A, At 100° C.; B, at 109° C.

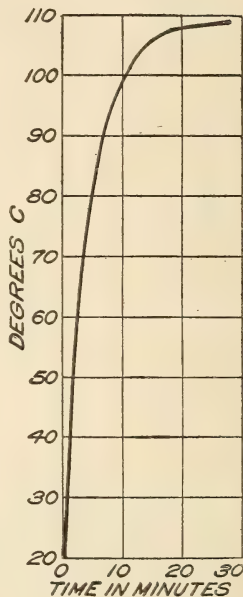


FIG. 30.—Time-temperature relations for asparagus in 2 per cent brine when processed in quart glass jars at 109° C. This curve was plotted from temperature readings made at intervals of 1 minute.

the pack and the comparative effects of water and of brine upon the rate of change of temperature. Tests relating to the rate of cooling both in air and in water under these different conditions were also made. No perceptible differences were observed when water and when brine were used, or when different kinds of packs, viz, whole tips or one-half inch pieces, were employed. One set of curves, there-

fore, illustrates what was obtained in each case. Figures 27 to 30 show the curves for asparagus prepared by washing, cutting the stalks into one-half inch pieces, and packing into the containers, after which 2 per cent brine was added to fill the interspaces.

It will be noted that the curves for asparagus do not differ essentially from those of string beans. The cooling in air and in water also gave curves entirely similar to those of string beans.

Asparagus does not contain any large amount of soluble colloidal materials to cook out and change the viscosity of the surrounding liquid to any great extent, although it easily collapses when it is cooked too long or at too high a temperature.

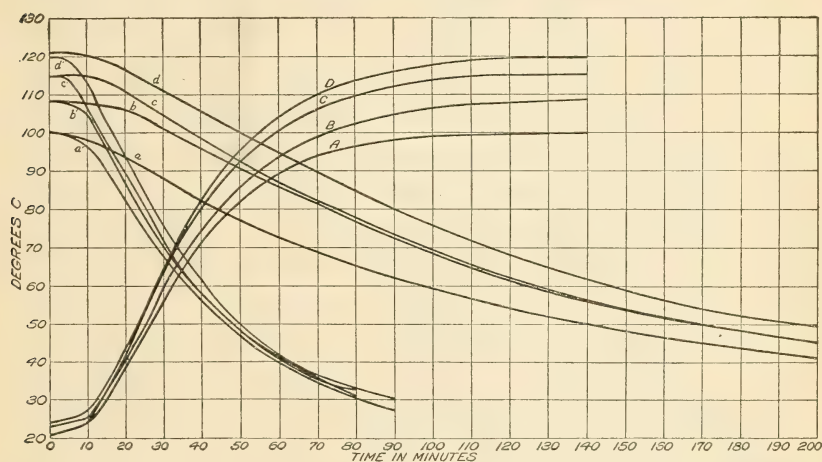


FIG. 31.—Time-temperature relations for sweet corn (Maine style) when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in air and in water. The curves representing the rise in temperature during processing and the fall in temperature during cooling in water were plotted from readings made at intervals of 5 minutes; those for cooling in air, at intervals of 5 to 10 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall in temperature when cooled: a', From 100° in water at 15° C.; b', from 109° in water at 22° C.; c', from 116° in water at 21° C.; d', from 121° in water at 18° C.; a, from 100° in air at 22° to 26° C.; b, from 109° in air at 25° to 28° C.; c, from 116° in air at 25° to 28° C.; d, from 121° in air at 25° to 28° C.

SWEET CORN.

The variety of corn used in these tests was Stowell's Evergreen. The corn was picked the same day that the test was made, and only ears that were in prime condition for canning were used. It was husked, the silks removed with a coarse brush, washed, and then cut off the cob "Maine style," i. e., about one-third of the grain was cut away with a sharp knife and then the rest scraped from the cob. A liquor of 2 per cent salt and 6 per cent sugar was prepared and added to the corn in the can to give the proportion of 5 parts of corn to 1 part of liquor. It was then processed in the various containers at the different temperatures, as in the previous experiments. Figures 31 to 34 show the results of these tests.

These curves indicate that the heat penetrates into the cans very slowly. It requires two hours to approach the temperature of the retort in a No. 2 tin can and nearly three hours to reach the same temperature in the No. 3 can. In one and one-half hours the pint glass jar approaches the temperature of the retort and in about two hours the same temperature is reached in the quart glass jar. It is very evident, therefore, that little convection is taking place. Convection is prevented in part by the finely divided condition of the corn, and further by the viscous condition of the liquor, which results from gelatinization of the starch. The differences in the rate of change of temperature between the No. 2 and No. 3 tin cans are very great, indicating the necessity of different processing periods.

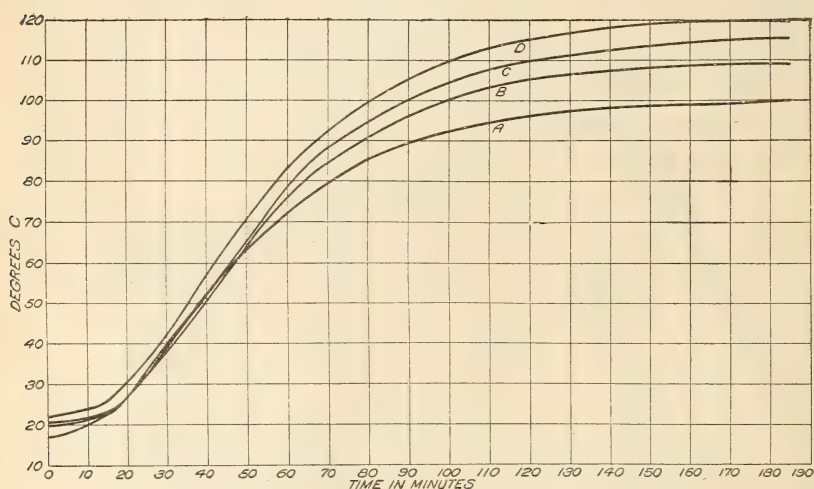


FIG. 32.—Time-temperature relations for sweet corn (Maine style) when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

The difficulty of getting the heat to the center of a No. 3 can and the quart glass jars is so great that it is advantageous to can sweet corn in No. 2 tin cans or in pint glass jars. It is to be noted that the low conductivity of the glass ceases to be a factor here, and the rate of change of temperature follows more nearly the order of the diameters of the containers, i. e., the pint glass jar is fastest, then the No. 2 tin can, the quart jar next, and the No. 3 can slowest. This order is quite different from that of string beans.

Stirring the material would very greatly aid in getting the heat to the center of the can for corn prepared in the Maine style, and for this reason agitating cookers might be especially advantageous for handling corn packed in this manner.

Figure 31 shows the record of cooling for a No. 2 tin can in air and in water. The cooling in air is considerably slower than that of string beans, but the differences are not so great as might be expected from the differences in the rise in temperature. The cooling in water, although very much faster than the cooling in air, is still very slow in comparison to the cooling of string beans in water. It requires about 1 hour and 20 minutes for the corn to fall to 30° C. in these tests, whereas string beans required only 10 to 15 minutes. These differences in the rate of cooling in air and in water. It required about tremely important when it is remembered that high temperatures seriously affect the appearance and flavor of the corn.

Attention is again called to the fact that when the steam is cut

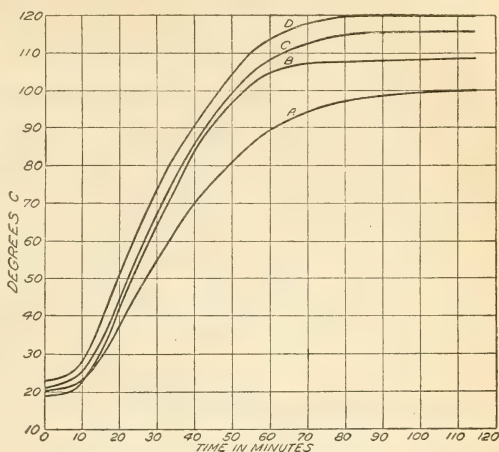


FIG. 33.—Time-temperature relations for sweet corn (Maine style) when processed in pint glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C. (the proportion of corn to liquor in this case, unfortunately, was less than in those processed at the higher temperatures); B, at 109° C.; C, at 116° C.; D, at 121° C.

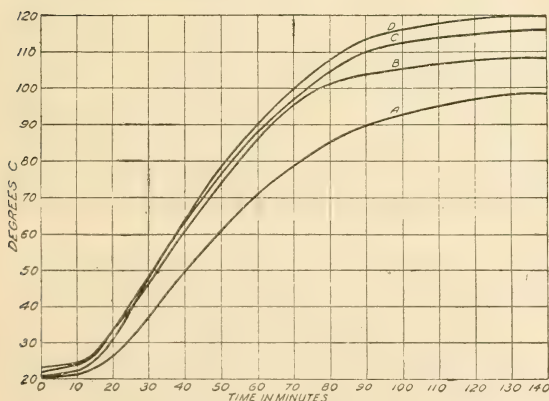


FIG. 34.—Time-temperature relations for sweet corn (Maine style) when processed in quart glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C. (the proportion of corn to liquor in this case, unfortunately, was less than in those processed at the higher temperatures); B, at 109° C.; C, at 116° C.; D, at 121° C.

off at the end of the processing period the temperature of the jars falls from any temperature above 100° to 100° C. as rapidly as the temperature in the retort. This is important, especially in substances like corn, as sterilizing temperatures are maintained for much shorter periods than in tightly sealed cans.

VARIETAL DIFFERENCES.

Other tests were made to determine

whether varietal differences in corn had any effect upon the rate of change of temperature at the center of the can. Comparison was made of White Dent field corn, Golden Bantam, Country Gentleman, Stowell's Evergreen, and Crosby's Early. No differences of importance were observed when these varieties were prepared in Maine style. Tests with corn at different stages of maturity were not made, although this would have been of interest, since the starch content is known to increase during the approach to maturity.

It is not probable, however, that the differences in maturity generally permissible in canning practice would have any effect.

MAINE STYLE AND MARYLAND STYLE COMPARED.

Having found that differences in the fineness of division of particles affects the rate of change of temperature, tests were made for the

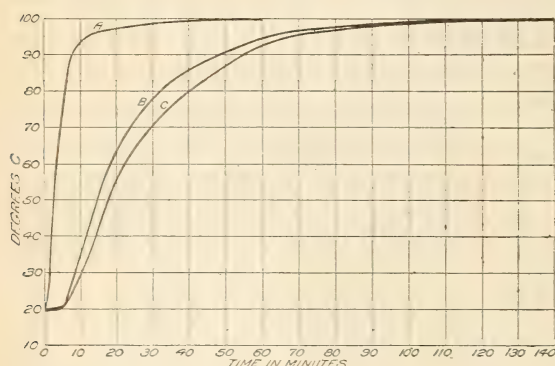


FIG. 35.—Time-temperature relations for sweet corn (Maine style and Maryland style) processed at 100° C. in No. 2 tin cans. These curves were plotted from temperature readings made at intervals of 5 minutes. Proportion of corn to liquor: A, Maryland style, 2.1:1; B, Maine style, 2.1:1; C, Maine style, 3.1:1.

cans were used, and the same proportion of corn and liquor (by weight) was used in each case. The proportion of corn to liquor was 2.1 to 1. The results when processed in the water bath at 100° C. are shown in figure 35.

A higher rate of change of temperature is noted in the Maryland style than in the Maine style, as the result of the greater freedom of movement of the liquor filling the interspaces. There was some convection in each case, but the results probably would have been entirely different if the proportion of water to corn had been other than that used in these tests. Such marked differences as are shown in these experiments should be borne in mind when processing periods are under consideration.

EFFECT OF DIFFERENT PROPORTIONS OF LIQUOR.

Tests were made to determine the effect of different proportions of corn to liquor upon the rate at which heat passes into the can. The

purpose of comparing the Maine style and Maryland style of packing. Stowell's Evergreen was the variety used for these tests. In the Maine style the corn was prepared as already described. In the Maryland style the corn was prepared by cutting the grains from the cob as nearly whole as possible, without scraping. No. 2 tin

variety used in these tests was Stowell's Evergreen. The corn was prepared in the Maine style, placed in No. 2 tin cans, and processed at 100°C . The proportions of corn to liquor used in these tests were 1 to 0, 1 to 1, 2 to 1, 3 to 1, 4 to 1, and 5 to 1. The results are shown in figure 36.

In the can having the proportion of 1 to 1 there is a very rapid rise in temperature, due largely to convection which occurs in the liquid. The last two or three degrees go very slowly, however, owing to gelatinization of the starch, which increases the viscosity to such an extent as to counteract the force, small at this point, tending to cause convection. In the can having the proportion of 2 to 1 there is a marked falling off in the rate throughout the curve. There is considerable convection here, but it is less pronounced and stops sooner than in cans having the proportion of 1 to 1. Likewise in the 4 to 1 and in the 5 to 1 there is a further falling off of the rate of temperature rise. In these cans convection is further reduced and probably plays only a small part in the 5 to 1 cans. It is noted that the temperature at the center of the can approaches that of the bath more quickly in the case of the corn alone than in the proportion of 5 to 1, 4 to 1, or 3 to 1. This apparent inconsistency is easily understood when

one realizes what is taking place in the four cans. In the can having the proportion of 5 to 1 there is little, if any, convection, for the going into solution of the starch forms a mass having so small an amount of free liquid that very little or no convection takes place. In the proportion of 4 to 1 some convection occurs, but it is checked early in the process by the same cause. The same in general is true in the case of 3 to 1, but more time is required to arrest the convection currents. In the corn alone there is no free liquor in which convection can take place, but there is a saturated air more or less continuous from the center to the outside of the material, which certainly allows some convection, thus accounting for the more rapid rise in the corn alone than in the 4 to 1 and the 5 to 1 cans. If the material in the can of corn alone had been packed down tightly the curve would have been considerably different.

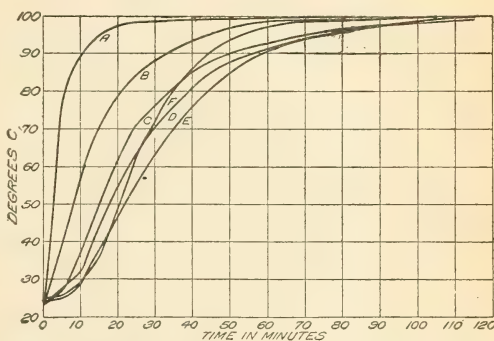


FIG. 36.—Time-temperature relations for sweet corn (Maine style) with different proportions of liquor processed in No. 2 tin cans at 100°C . These curves were plotted from temperature readings made at intervals of 5 minutes. Proportion of corn to liquor: A, 1:1; B, 2:1; C, 3:1; D, 4:1; E, 5:1; F, corn alone.

PUMPKIN.

The Connecticut Pie pumpkin was used in the tests. The pumpkins were washed, split into halves, and the seeds removed. They

were then cut into strips, the outer rind removed, and the pieces steamed for 30 minutes. After cooling, the pieces were ground in a food chopper in order to get a uniform pulp. This material, now in the form of pie stock, was packed in the cans. Figures 37 to 40 show the results of these tests.

As might be expected, the rate of rise in temperature is very slow, there being insufficient

free liquid to make possible any great amount of convection. The time-temperature curves for pumpkin are very similar to those for

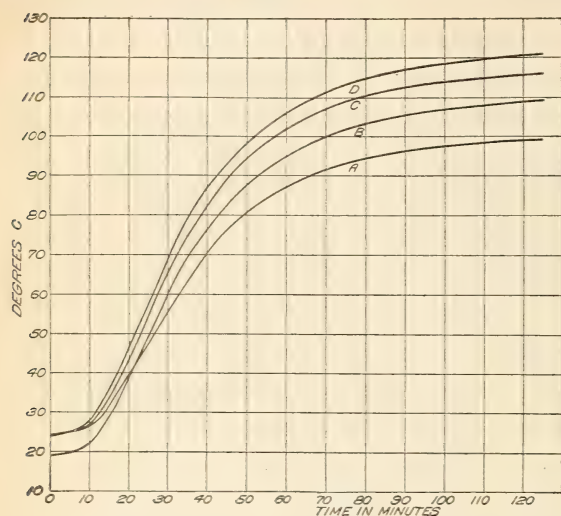


FIG. 37.—Time-temperature relations for pumpkin processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

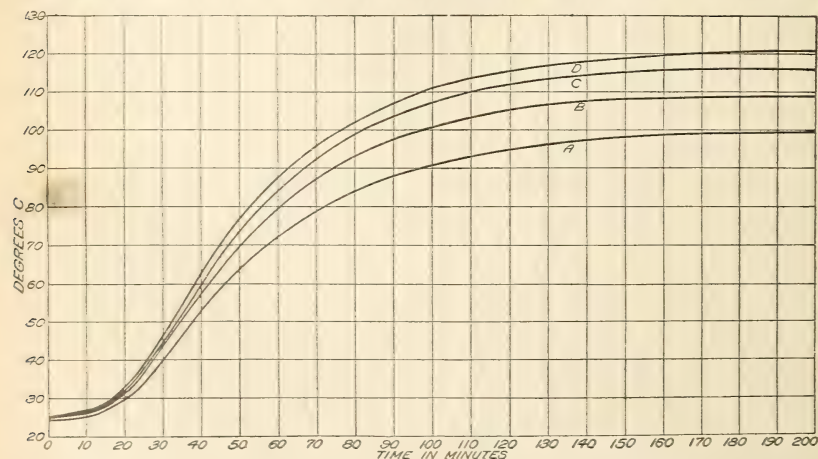


FIG. 38.—Time-temperature relations for pumpkin processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

sweet corn. Cooling tests in water were not made, and the curves for the cooling in air are omitted, as they add nothing of value.

The differences in the containers are the same as in the case of the sweet corn. The temperature rises fastest in the pint glass jar, the No. 2 tin can next, then the quart glass jar, and most slowly in the No. 3 tin can. The retarding influence of the glass ceases to be a factor here. This is because the conductivity of either the tin or the glass is greater than the conductivity of the material. Hence, the rate of temperature change at the center of the can follows the order of the diameters of the containers. This is true for sweet corn and pumpkin and also for sweet potatoes, as will be seen later. Sometimes pumpkin is concentrated before being canned. Evaporating the pulp to half its original volume would probably have only a small effect upon the rate of change of temperature. There is very little convection in the

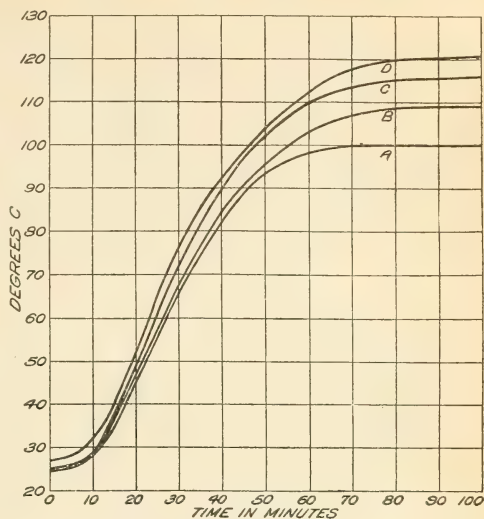


FIG. 39.—Time-temperature relations for pumpkin when processed in pint glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

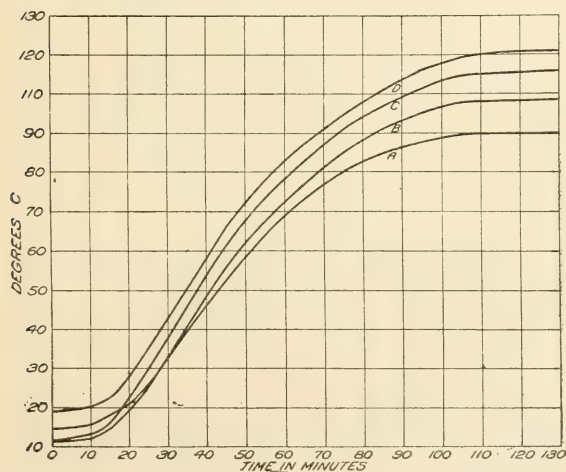


FIG. 40.—Time-temperature relations for pumpkin when processed in quart glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

material as thus prepared, so it is almost certain that evaporation to one-half would make it only slightly slower.

Some experiments were made to determine what effect cooking before filling into the can would have upon the temperature changes in the can. Cans were filled with raw material ground in the food chopper and with material which had been steamed 30

minutes and then ground in the food chopper and given identical processing temperatures. No appreciable differences were observed.

Tests were also made with summer squash prepared as described for the pumpkin. The time-temperature curves are practically the same. These curves have been omitted to save space.

SWEET POTATOES.

The variety of sweet potato used in these tests was the Nancy Hall. The potatoes were washed and steamed 30 minutes. After peeling they were allowed to cool and were then ground in a food chopper in order to get a uniform mash, commonly known as "pie stock."

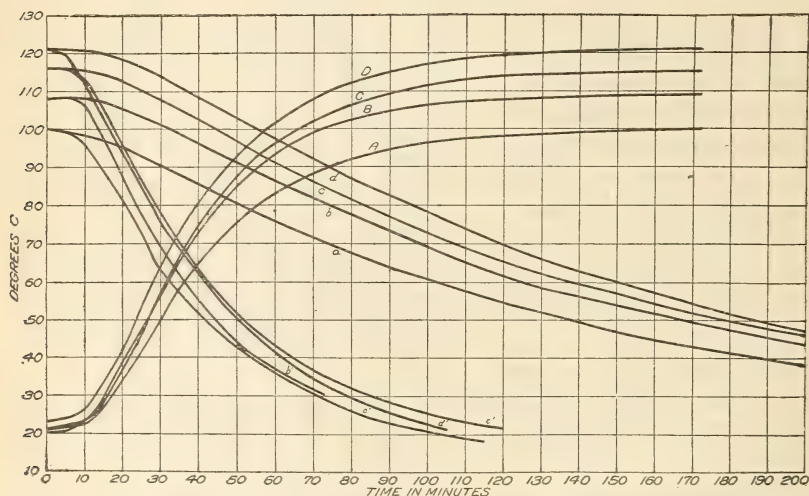


FIG. 41.—Time-temperature relations for sweet potatoes when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in air and in water. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C. Fall in temperature when cooled: a', From 100° in water at 15° C.; b', from 109° in water at 15° C.; c', from 116° in water at 15° C.; d', from 121° in water at 15° C.; a, from 100° in air at 20° to 24° C.; b, from 109° in air at 20° to 24° C.; c, from 116° in air at 25° to 25½° C.; d, from 121° in air at 25° to 25½° C.

Tests in glass were incomplete; hence time-temperature curves for these have been omitted. Figures 41 and 42 show the rise in temperature and also the cooling in air and in water for both No. 2 and No. 3 tin cans.

It will be seen that the temperature changes at the center of the can are very slow, in most cases slightly slower than in pumpkin or sweet corn. The necessity of a considerably longer processing period for the No. 3 tin can than for the No. 2 is again emphasized. Owing to the firmness of the pack and the absence of free liquid, convection currents play no part in the temperature changes here. Therefore, rotating the can in order to stir the material, as in an

agitating cooker, would have much less effect with sweet potatoes than the same treatment with sweet corn.

COMPARISON OF RAW AND COOKED MATERIAL.

Tests with sweet potatoes ground in a food chopper and packed into the can raw and with material cooked 30 minutes, ground, and packed into the can were made, the processing being conducted under identical conditions. There were no appreciable differences in the rate of change of temperature in the can. It is apparent that the gelatinization of the starch has little effect if the nature of the material at the outset is such that convection is prevented.

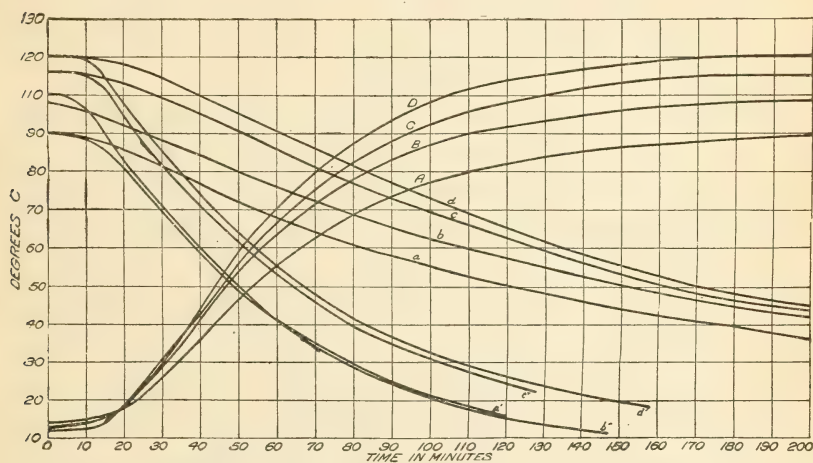


FIG. 42.—Time-temperature relations for sweet potatoes when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. and also when cooled in air and in water. These curves were plotted from temperature readings made at intervals of 5 minutes. Rise in temperature when processed: *A*, At 100° C.; *B*, at 109° C.; *C*, at 116° C.; *D*, at 121° C. Fall in temperature when cooled: *a'*, From 100° in water at 15° C.; *b'*, from 109° in water at 15° C.; *c'*, from 116° in water at 19° C.; *d'*, from 121° in water at 19° C.; *a*, from 100° in air at 18° to 22° C.; *b*, from 109° in air at 20° to 24° C.; *c*, from 116° in air at 25° to 25½° C.; *d*, from 121° in air at 25° to 25½° C.

PROCESSING FOR DIFFERENT LENGTHS OF TIME AT 116° C.

Figure 43 shows the result of a series of tests of No. 3 tin cans processed at 116° C. for 50, 60, 70, 80, 90, and 100 minutes and then put immediately into the air. The temperature of the air varied somewhat, so that the results are not exactly uniform. Two facts are brought out by this series of tests: (1) The temperature continues to rise for 20 to 30 minutes after the cans are put into the air; (2) at this processing temperature 90 to 100 minutes are required to carry the temperature at the center of the can to 100° C., or above. This is simply a "cut and try" method of finding the length of time necessary to sterilize any particular pack of canned material. If the cans had been left in the retort or put into water, the results would have

been entirely different. If the initial temperature of the material when put into the can had been higher, the maximum temperature attained would also have been higher.

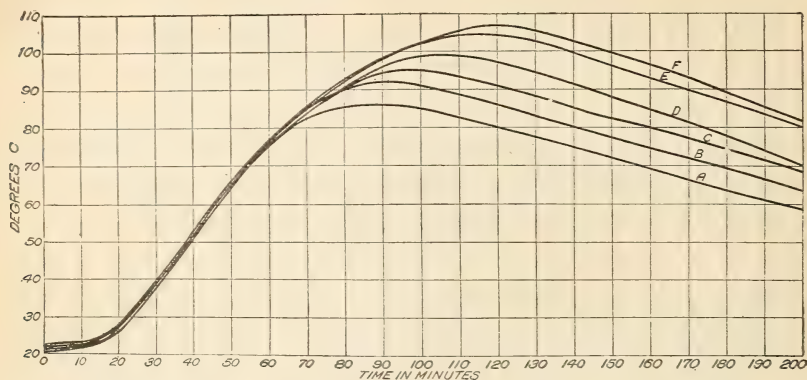


FIG. 43.—Time-temperature relations for sweet potatoes when processed in No. 3 tin cans at 116° C. for 50, 60, 70, 80, 90, and 100 minutes and then removed to the air at 20° to 25° C. These curves were plotted from readings made at intervals of 5 minutes. Temperature curve when processed and placed in air: A, For 50 minutes; B, for 60 minutes; C, for 70 minutes; D, for 80 minutes; E, for 90 minutes; F, for 100 minutes.

It is obvious that the initial temperature in the can should be uniform in all cans of the pack where the same processing is to be given, and the initial temperature should also be as high as pos-

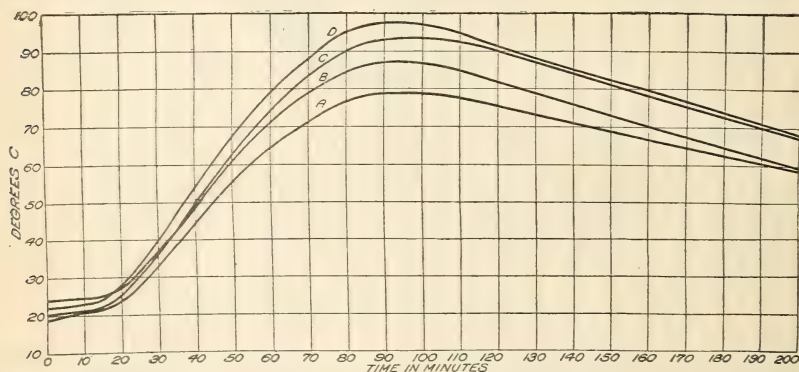


FIG. 44.—Time-temperature relations for sweet potatoes when processed in No. 3 tin cans for 1 hour at 100°, 109°, 116°, and 121° C. and then removed to the air at 20° to 25° C. These curves were plotted from readings made at intervals of 5 minutes. Temperature curves when processed for one hour: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

sible, in order that the processing period may be shortened. Starting at a temperature higher than that of the room is to be recommended.

PROCESSING FOR ONE HOUR AT DIFFERENT TEMPERATURES.

Figure 44 shows curves for No. 3 tin cans of sweet potatoes processed at 100°, 109°, 116°, and 121° C. for 1 hour in the retort, or

bath, and then removed immediately to the air. The temperature at the center of the can continues to rise for 20 to 30 minutes after it is put in the air. When the can is processed for 1 hour at 121° the temperature just approaches 100° C. If the can had been left in the retort instead of being put in the air, the temperature would have gone higher. This shows again the importance and necessity of knowing what temperatures are reached during the processing period. Such factors as these are often overlooked, when they are of very great importance. If the initial temperature had been different, it would have affected the maximum temperature attained. In processing sweet potatoes in No. 3 tin cans it is of very great importance to have the initial temperature as high as practicable.

TOMATOES.

The tomatoes used in these tests were of a special disease-resistant variety being studied at the Arlington Experimental Farm. They were fully ripened and of medium size. After scalding for two minutes in boiling water they were plunged into cold water to be peeled. After peeling they were packed into the cans as nearly whole as possible. No water or other liquid was added. Tests in both tin and glass containers were made, as usual. Cooling tests in air only were made. The temperature of

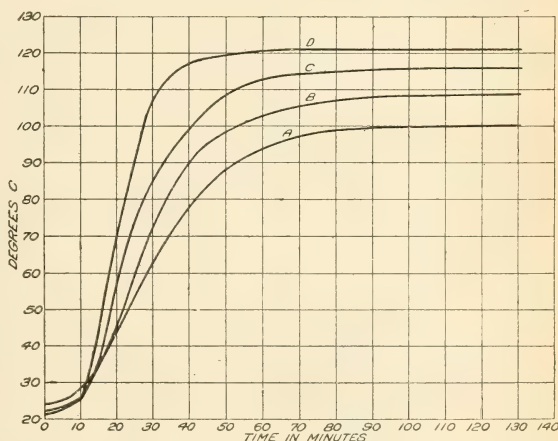


FIG. 45.—Time-temperature relations for tomatoes when processed in No. 2 tin cans at 100° , 109° , 116° , and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: *A*, At 100° C.; *B*, at 109° C.; *C*, at 116° C.; *D*, at 121° C.

the air varied considerably, so that the cooling in the various tests is not strictly comparable, and the curves were therefore omitted from the charts. The results showed, however, that the cooling would be somewhat slower than for string beans. Figures 45 to 48 show the results of these tests. Individual curves represent tests of a single can. Duplicate cans varied considerably, owing perhaps to inability to pack them exactly alike. The curves illustrate average results quite well, however.

The rate of change in temperature is faster than in pumpkin or sweet corn, but very much slower than in string beans. At 100° C.

it requires about 1 hour and 30 minutes to approach the temperature of the bath. At 109° C. it requires about 1 hour and 20 minutes,

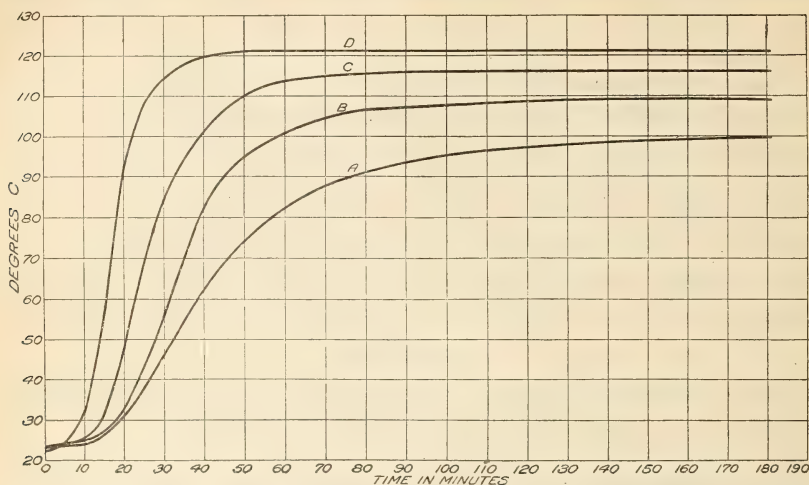


FIG. 46.—Time-temperature relations for tomatoes when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

at 116° about 1 hour and 10 minutes, and at 121° it requires 1 hour to reach the processing temperature in a No. 2 tin can. Similar

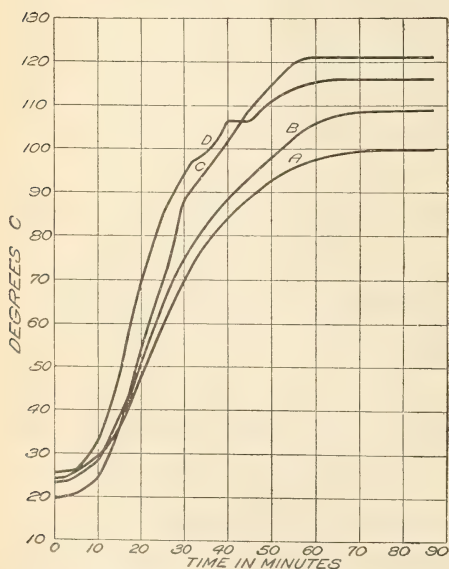


FIG. 47.—Time-temperature relations for tomatoes when processed in pint glass jars at 100°, 109°, 116°, and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

results are noticed in the No. 3 tin cans and in the pint and quart glass jars. A shorter time is required to reach the temperature of the retort at 121° than at any lower processing temperature. With many vegetables and fruits there is a slowing down in the rate of rise as the temperature goes higher, owing to the going into solution of starch, protein, or other material, which changes the viscosity of the material. This change in viscosity interferes with convection, and so the process is slowed down. A change of exactly the opposite character is taking place in the tomato. The tomato fruit is very succulent, and its tissues are easily broken down at high tempera-

tures. There is very little starch, pectin, or other readily soluble colloidal material in the tomato. It consists of organic acids and sugars, with insoluble cell tissues and a large amount of water. As a high temperature is reached the tissues begin to collapse, leaving a free liquid in which convection can take place. This explains the greater rate of temperature change at the higher processing temperature than at the lower.

Such high temperatures as 109° , 116° , and 121° C. are not necessary for the sterilization of the tomato, and the results are only of theoretical interest. Where it is of importance to keep the tissues of the material intact high temperatures should be avoided. It is of interest and importance to know just what temperatures are reached when the various cans are processed for 10, 15, 20, 25, 30, and 40 minutes each, but this work has not yet been completed.

The irregularities noted in the curves for tomatoes in the glass containers are due to the tendency of the material to rise to the top when it collapses under the high temperatures. The solid portion as it rises may for a time surround the thermometer, preventing

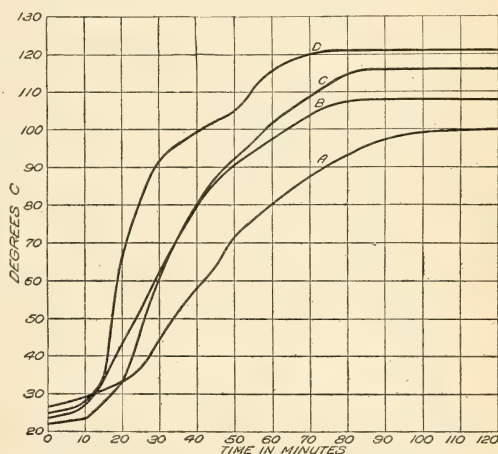


FIG. 48.—Time-temperature relations for tomatoes when processed in quart glass jars at 100° , 109° , 116° , and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

convection, but later rises still higher, leaving the bulb of the thermometer in a liquid that is more or less free.

CABBAGE.

All cabbage plants used in these tests had firm heads, and the outer leaves were discarded. The heads were sliced somewhat coarser than for sauerkraut, with a rotary slicing machine. The sliced material was then blanched in flowing steam for 10 minutes, after which it was packed into the cans and enough water added to fill the interspaces. The results are shown in figures 49 and 50. The wide variation is due to inability to pack the cans exactly alike. In general when packed in this way the rate of change of temperature at the center of the can is very much slower than that of string beans, but considerably faster than that of sweet corn. Cabbage is the

only one of the leafy vegetables that has been included in these tests. The rate of change of temperature at the center of the can in the leafy vegetables depends upon the nature of the packing. If the cabbage in this case had been cut coarser and a little more water had been added, the rate of change would have been very much faster. On the other hand, if the material had been sliced finer and packed into the can a little closer, the rate would have been slower. Any alteration of the packing which would affect convection would affect the rate of change of temperature at the center of the can. In the leafy vegetables almost any results may be obtained between that of

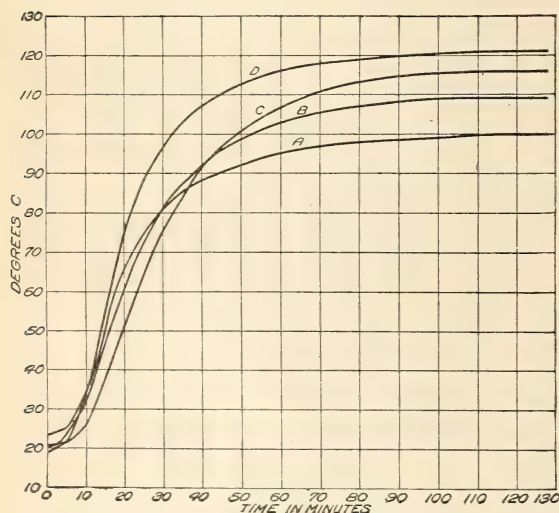


FIG. 49.—Time-temperature relations for cabbage when processed in No. 2 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

string beans and sweet corn. As usually packed, however, the changes are perhaps quite slow. This, again, shows how important it is to know how rapidly the temperature in the can approaches that of the retort.

FACTORS AFFECTING THE CHANGE OF TEMPERATURE AT THE CENTER OF THE CAN.

In considering the factors affecting the rate of change of temperature in the can the laws of heat transmission, especially the rapidity of

convection and the slowness of conduction and radiation, should be held in mind. From all the preceding experiments the following facts seem clear.

The first important factor is the size and nature of the container. If the rate at which the material in the can transmits heat is slower than the conductivity of the walls of the container, then the nature of the container ceases to be an important factor and the diameter of the container is the chief factor. If the rate at which the material carries heat to the center of the can is faster than the conductivity of the walls of the container, then the nature of the container is important and variation in its conductivity affects the temperature changes at the center of the can. Thus in string beans there is a difference in the rate of change of temperature in the tin and glass

due to the differences in the conductivity of the walls of the container, but in sweet corn the rate of change of temperature follows more nearly the order of the diameter of the container, the glass not being an important factor. The diameter of the container is of very much less importance in material where there is a free liquid in which convection carries the heat rapidly to the center of the can. Thus the difference in the rate of change of temperature in No. 2 and in No. 3 tin cans is so small in string beans that only slight differences in the processing periods are necessary.

Variations in the composition of the material are of importance when such variations affect convection. If the material is of such a nature that no convection occurs, its composition may vary widely without greatly affecting the temperature changes in the can. Thus

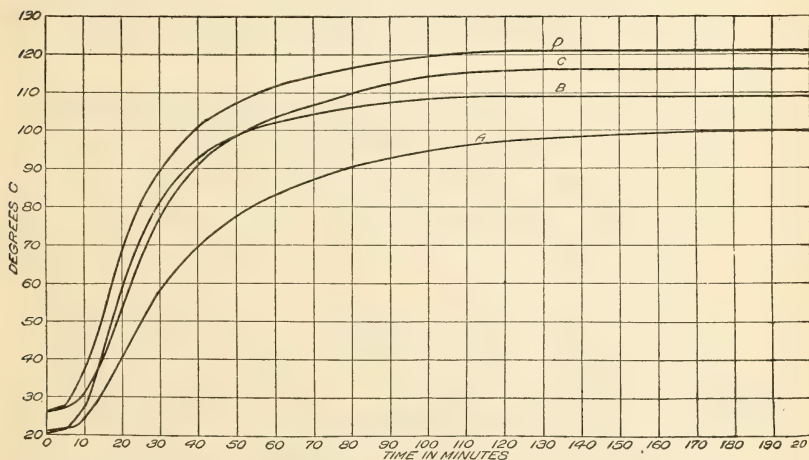


FIG. 50.—Time-temperature relations for cabbage when processed in No. 3 tin cans at 100°, 109°, 116°, and 121° C. These curves were plotted from readings made at intervals of 5 minutes. Rise in temperature when processed: A, At 100° C.; B, at 109° C.; C, at 116° C.; D, at 121° C.

sweet potatoes and pumpkin, though of very different chemical composition, have similar time-temperature curves. The going into solution of starch may change the viscosity of the material and hence affect the temperature changes in the can, but changes in the physical nature of the starch have very little effect if the character of the pack at the outset is such that no convection can occur. In some cases there may be the cooking out of soluble proteins, pectins, or other viscous materials which would interfere with convection. Variations of materials in this respect must be considered in processing. Usually in processing where there is a breaking up of the material the rate of change of temperature becomes slower, but in the tomato the opposite is true, because the tomato contains little starch, pectin, or other mucilaginous material. The liquid becomes free, thus allowing convection.

The nature of the pack is one of the most important factors affecting the rate of change of temperature. In any material of any composition which is so packed that there is a free liquid filling in the interspaces between the pieces of material in the pack there is a very rapid change in temperature during processing. The temperature of the material approaches the temperature of the bath or retort very quickly. Any variation in the method of packing which interferes with convection alters the rate of change of temperature in the center of the can. The proportion of liquid to material is important, as has been shown under "Sweet corn." The fineness of division of the material is of importance because of the increased effect of surface tension in finely divided material. The fineness of division also affects the proportion of liquid to material.

The blanching or precooking affects the temperature changes if it in any way alters the nature or proportion of free liquid in the ma-

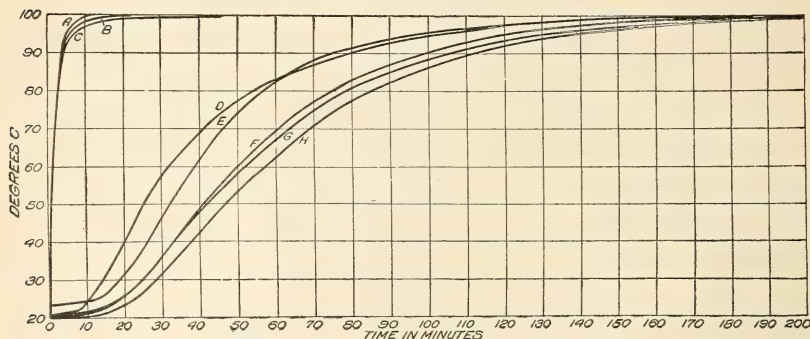


FIG. 51.—Time-temperature relations for different vegetables when processed in No. 3 tin cans at 100° C., as compared with distilled water. Curves A, B, and C were plotted from readings made at intervals of 1 minute, and curves D to H were plotted from readings made at intervals of 5 minutes. A, Distilled water; B, string beans; C, soy beans; D, cabbage; E, tomatoes; F, pumpkin; G, corn; H, sweet potatoes.

terial. Blanching the leafy vegetables would enable a closer pack to be made and would thus make the rate of change of temperature slower.

The heating and cooling medium is of importance. When the container is heated or cooled in the air the process is very slow. When it is heated in water or steam and when cooled in water, the process is very rapid, depending upon the other factors already pointed out.

Figure 51 shows curves for a large number of vegetables processed in No. 3 tin cans at 100° C. They fall pretty distinctly into two groups. The group having a free liquid with a consequent rapid rise in temperature contains by far the larger proportion of fruits and vegetables. This group includes string beans, Lima beans, soy beans, peas, and asparagus. In the second group, having

very little free liquid, the rate of change of temperature is very slow. In this group are sweet potatoes, sweet corn, pumpkins, and summer squash. Tomato and cabbage form a somewhat intermediate group.

INTERMITTENT PROCESSING.

Since sterilization by the intermittent process depends not only upon the maximum temperature attained, but also upon the length of the interval between processing periods and upon the temperature during this interval, it becomes of very great importance to understand thoroughly the time-temperature relations throughout the entire process. The first processing is supposed to destroy all vegetative forms of bacteria, and during the following interval any spores which may be present germinate and are killed during the second processing period. Any spores failing to germinate during the first interval are expected to germinate during the second interval and so are destroyed in the vegetative form during the third process. If the temperature during these intervals should be either too high or too low for the germination of any spores, then the whole process might fail. It is also known that spores of certain bacteria under optimum conditions germinate very quickly, multiply, and again form spores in a period of less than 24 hours. These facts make it highly important to understand the entire time-temperature relations.

In the experiments on the intermittent process a record of the processing temperatures, the temperature of the air to which the cans were removed after processing, and the temperature at the center of the can was kept during the entire period of 72 hours. The length of the processing period was exactly 1 hour. This treatment was given once on each of three successive days. String beans, corn, soy beans, and sweet potatoes were tested in this way.

STRING BEANS.

The variety of bean used was the Green Pod Stringless. The beans were washed and broken into pieces 1 to 1½ inches in length and blanched for five minutes in the boiling-water bath. They were cooled and packed into the cans and enough 2 per cent brine added to cover the material. They were then processed, as above stated. Figure 52 shows the results for No. 2 and No. 3 tin cans, and for pint and quart glass jars for the entire period.

During the first processing the temperature of the No. 2 and No. 3 tin cans approached that of the bath in about 10 minutes, the pint jar in about 25 minutes, and the quart jar in 30 minutes. The order of their heating up was No. 2 tin cans first, No. 3 tin cans next, then pint glass jars and quart glass jars last. The No. 2 and No. 3 tin

cans remained at about 100° C. for a period varying between 40 and 50 minutes each, and the pint and quart glass jars for a period between 25 and 30 minutes. At the end of one hour they were taken immediately from the bath and put in the air. The cooling was slow. The temperature fell to 60° C., as follows: No. 2 tin can, 1 hour and 25 minutes; No. 3 tin cans, 1 hour and 40 minutes; pint glass jars, 1

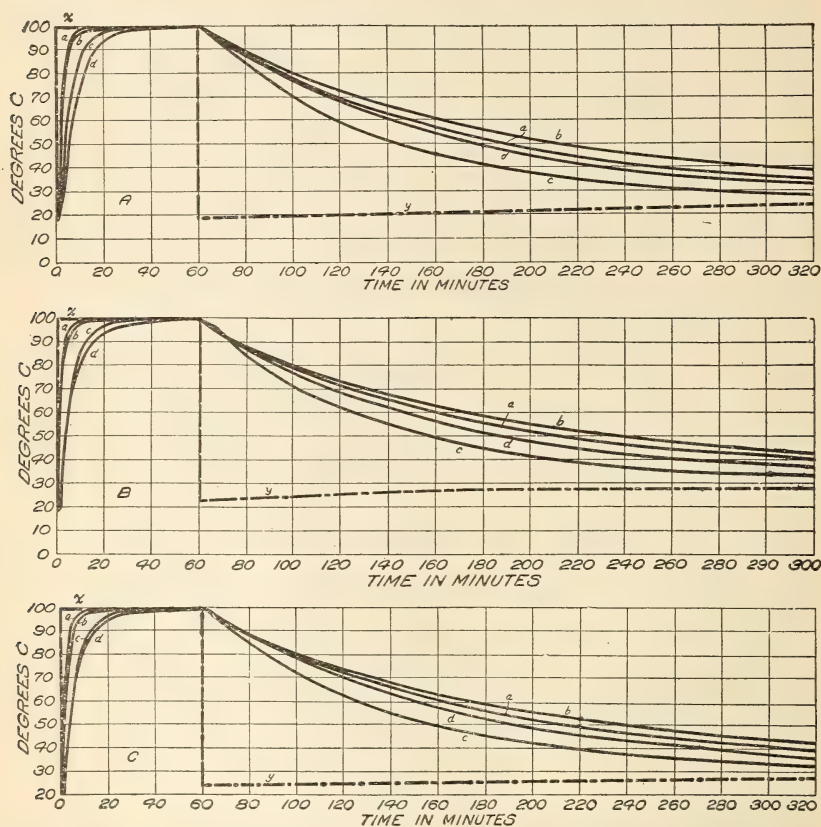


FIG. 52.—Time-temperature relations for string beans in various containers when processed for 1 hour on each of three successive days (the intermittent process) at 100° C. in the boiling-water bath: A, First day; B, second day; C, third day; a, No. 2 tin cans; b, No. 3 tin cans; c, pint glass jars; d, quart glass jars; x, temperature curve for water bath; y, temperature curve for room. The interval between the end of the curves in A and the beginning of the curves in B was 18 hours and 40 minutes. The same period of time elapsed between the end of the curves in B and the beginning of the curves in C.

hour; and the quart glass jars 1 hour and 20 minutes. The order of their cooling was pint jars fastest, quart jars next, then the No. 2 tin cans, and No. 3 tin cans slowest.

Since the optimum temperature for the germination of most bacterial spores is between 30° and 40° C., the length of time that the can remains at this temperature is important. It was found in this

case to be between 1 and $1\frac{1}{2}$ hours, which is probably sufficient to allow the germination of most spores. The temperature remained below 30° for the remainder of the 24 hours.

During the second processing the time-temperature relations were practically the same as during the first. The rate of change of temperature was very slightly slower, but this was insignificant.

The result of the third processing was essentially the same as the second. There was no change in the first heating, which affected materially the rate of change of temperature in the second and third processing.

SWEET CORN.

The variety of sweet corn used in these tests was Stowell's Evergreen. Ears which were in prime condition for canning were selected in the field. They were husked, the silks were removed with a coarse brush, and they were then washed in water. The corn was prepared "Maine style" and enough brine-sugar solution (2 per cent salt and 6 per cent sugar) was added to make the proportion 4.5 of corn to 1 of liquor. It was then processed for exactly one hour on each of three successive days. The time-temperature curves for No. 2 and No. 3 tin cans and for pint and quart glass jars are shown in figure 53.

The results shown here are very different from those for string beans. The temperature, instead of rising rapidly, went up very slowly. In no case did it reach 100° C. The temperature was rising when the cans were removed from the bath and continued to rise for a considerable time after being placed in the air. The pint glass jar went highest, the No. 2 tin can next, then the quart glass jar, with the No. 3 tin can lowest. The order in which they heated up was different from that of string beans. All the cans went above 80° C., which is sufficient to destroy most vegetative forms of bacteria. The cooling was quite slow. The temperature fell to 60° C. about as follows: No. 2 tin can, 2 hours and 5 minutes; No. 3 tin can, 2 hours and 20 minutes; pint glass jar, 1 hour and 25 minutes; and quart glass jar, 1 hour and 50 minutes. The temperature of the containers remained between 30° and 40° C., as follows: No. 2 and No. 3 tin cans, 3 hours; the pint glass jars, 2 hours and 20 minutes; and the quart glass jars, 2 hours and 45 minutes. For the remainder of the time the temperature remained below 20° C., reaching 19° over night.

The initial temperature in the second processing was lower than in the first, and consequently the maximum temperature reached was lower. The curves took nearly the same form the second day as the first, showing that there had been but little alteration in the rate of change of temperature at the center of the can. The results were quite similar to those of the first processing. The results for the third processing were essentially the same as for the second.

SOY BEANS.

The variety of soy beans used in these tests was the Easy Cook. The beans were closely approaching maturity, as the pods were beginning to turn yellow. After gathering from the field they were placed upon trays and steamed five minutes at 100° C. This softened the pods so that they could be easily shelled by hand. The shelled

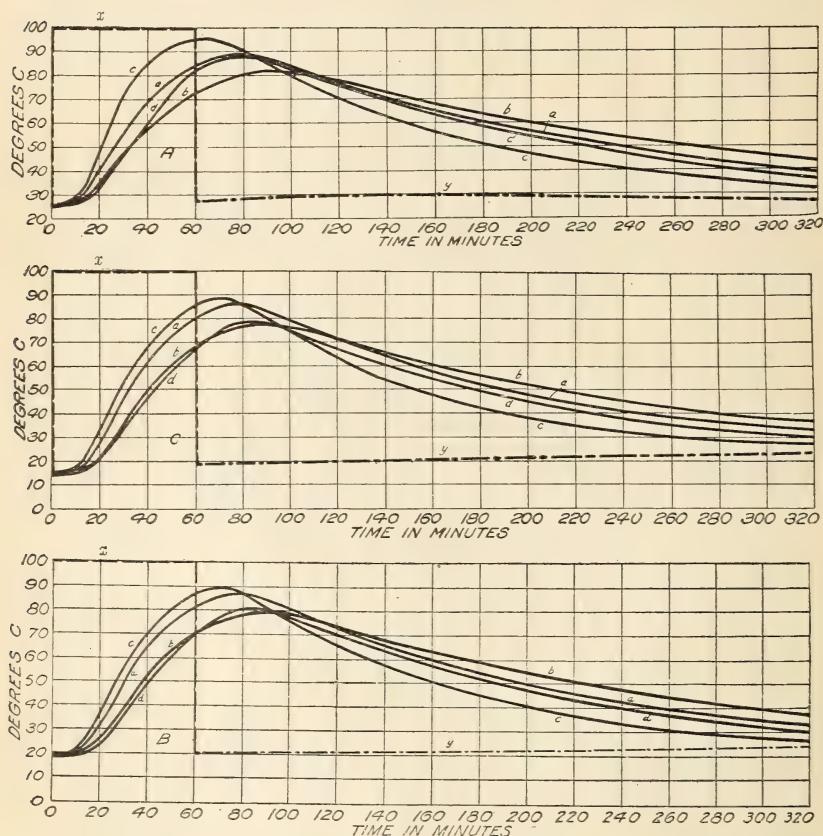


FIG. 53.—Time-temperature relations for sweet corn (Maine style) in various containers when processed for 1 hour on each of three successive days (the intermittent process) at 100° C. in the boiling-water bath: A, First day; B, second day; C, third day; a, No. 2 tin cans; b, No. 3 tin cans; c, pint glass jars; d, quart glass jars; x, temperature curve for water bath; y, temperature curve for room. The interval between the end of the curves in A and the beginning of the curves in B was 18 hours and 40 minutes. The same period of time elapsed between the end of the curves in B and the beginning of the curves in C.

beans were then placed in the cans and enough 3 per cent brine was added to cover the beans. They were then processed for exactly 1 hour on each of three successive days. Figure 54 shows the time-temperature record for the entire period of 72 hours for No. 2 and No. 3 tin cans and for pint and quart glass jars.

During the first processing there was a very rapid rise in temperature. The No. 2 tin can was fastest, with the No. 3 tin can next, then the pint glass jar with the quart glass jar slowest. The temperature approached 100° C. promptly, thus subjecting the material to that degree of heat for a considerable length of time. The cooling was rather slow, the pint jar being fastest, the quart jar next, then the

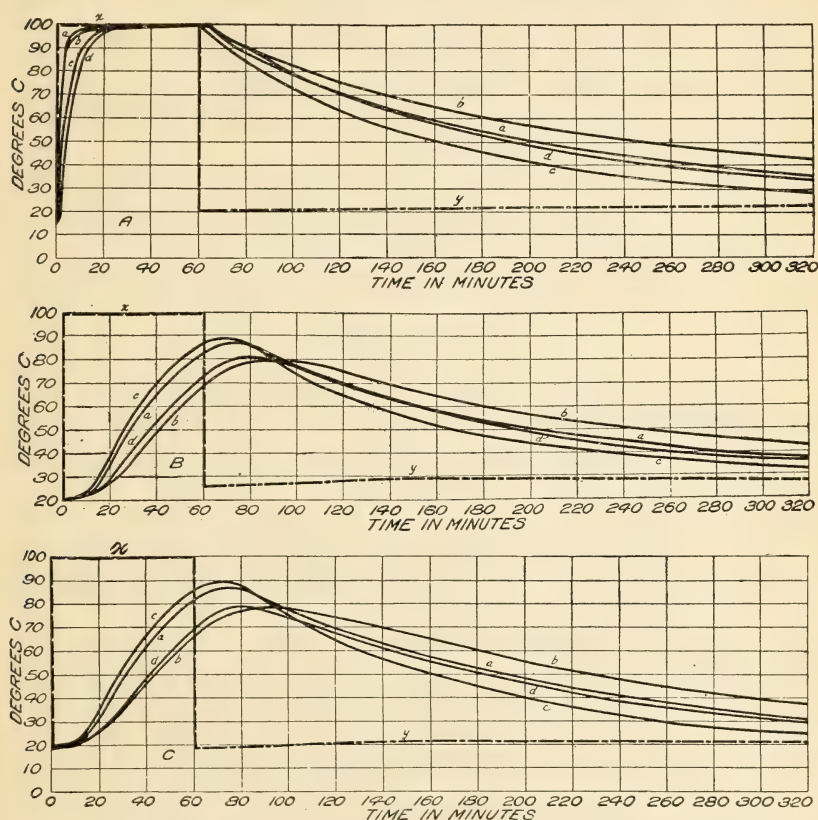


FIG. 54.—Time-temperature relations for soy beans (Easy Cook) in various containers when processed for 1 hour on each of three successive days (the intermittent process) at 100° C. in the boiling-water bath: A, First day; B, second day; C, third day; a, No. 2 tin cans; b, No. 3 tin cans; c, pint glass jars; d, quart glass jars; x, temperature curve for water bath; y, temperature curve for room. The interval between the end of the curves in A and the beginning of the curves in B was 18 hours and 40 minutes. The same period of time elapsed between the end of the curves in B and the beginning of the curves in C.

No. 2 tin can, with the No. 3 tin can slowest. The temperature fell to 60° C. in about 1 hour and 15 minutes in the pint glass jar, in $1\frac{1}{2}$ hours in the quart glass jar, in 1 hour and 35 minutes in the No. 2 tin can, and in 2 hours in the No. 3 tin can. The temperature remained between 30° and 40° C. in the different containers as follows: Pint glass jar, $1\frac{1}{2}$ hours; quart glass jar, 1 hour and 45 minutes;

No. 2 tin can, 2 hours and 25 minutes; and No. 3 tin can, 5 hours. The temperature fell to about 20° C. over night.

The time-temperature relations were entirely different in the processing on the second day. The temperature change was very much slower, as during the first processing the soluble proteins cooked out into the liquid to such an extent as to form a colloidal jelly. The change in consistency of the liquor was such that all convection was prevented in the second processing, and the heat passed in only by conduction. The temperature curves for the second heating were almost exactly the same as those of sweet corn. As in sweet corn, the temperature did not reach 100° C. at any time. The third processing was entirely similar to the second.

The very slow rate of change of temperature in the second and third periods of processing increased very greatly the possibility of an incomplete sterilization. Therefore, a period longer than 1 hour for the second and third processing would decrease the possibility of spoilage.

SWEET POTATOES.

The variety of sweet potato used in these tests was the Nancy Hall. The potatoes were washed, steamed for 30 minutes, peeled, and allowed to cool. They were then ground in the food chopper in order to get a uniform mash commonly known as "pie stock." This was placed in the cans and processed for 1 hour on each of three successive days, as in the preceding tests. Figure 55 shows the time-temperature records for No. 2 and No. 3 tin cans and for pint and quart glass jars.

The rate of rise in temperature was very slow, in no case reaching 100° C. during the processing. The maximum temperature attained, between 80° and 90° C. in the different containers, was reached at a considerable time after removal from the processing bath. The highest temperature was reached in the pint glass jar, the No. 2 tin can being next, then the quart glass jar, and the No. 3 tin can the lowest. The cooling was as might be expected from material of this sort. The temperature remained above 80° C. long enough to destroy most vegetative forms of bacteria. The results of the second and third period of processing were entirely similar to the first.

FACTORS INFLUENCING THE RATE OF CHANGE OF TEMPERATURE.

All those factors discussed under the heading "Single-period processing" apply to the first period of the intermittent process.

In addition to these factors the first period of the processing has an effect upon the material as treated during the second and third periods. As already observed in soy beans, there is often a change in the material during the first processing period which greatly affects

the temperature changes in the second period. To show clearly the differences that sometimes occur the following experiment was carried out.

Apples, pumpkin, and sweet potatoes were cut into half-inch cubes. These were placed raw in No. 3 tin cans and enough water added to cover the material. Also, soy beans were packed in cans in the same way and enough water was added to cover the material. These were

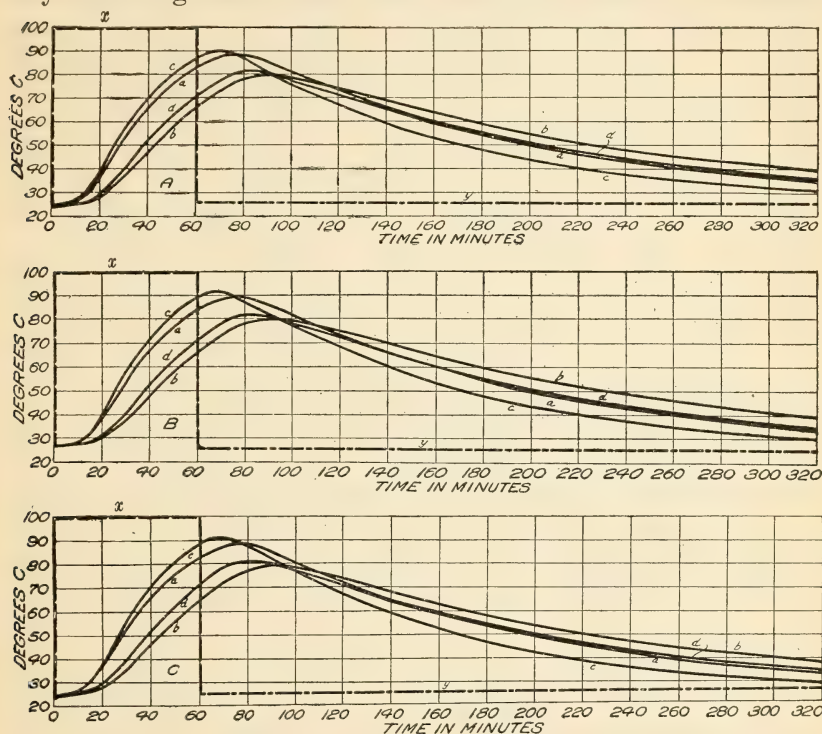


FIG. 55.—Time-temperature relations for sweet potatoes in various containers when processed for 1 hour on each of three successive days (the intermittent process) at 100° C. in the boiling-water bath: A, First day; B, second day; C, third day; a, No. 2 tin cans; b, No. 3 tin cans; c, pint glass jars; d, quart glass jars; x, temperature curve for water bath; y, temperature curve for room. The interval between the end of the curves in A and the beginning of the curves in B was 18 hours and 40 minutes. The same period of time elapsed between the end of the curves in B and the beginning of the curves in C.

then processed in the water bath for 1 hour. On the following day they were processed a second time. Figures 56 and 57 show the results.

In the pumpkin very little difference in the time-temperature curve for the first and second processing is noted. During the first period the rise of temperature was rapid, and it was almost equally so in the second processing.

In the apples there was a very marked slowing down of the rate of change of temperature, owing to the cooking out of pectin which changed the viscosity of the liquid filling the interspaces. The in-

creased viscosity interfered with convection and thus cut down the rate at which heat penetrated to the center of the can.

In the sweet potatoes the differences noted are extremely great. During the first processing the free liquid surrounding the pieces of

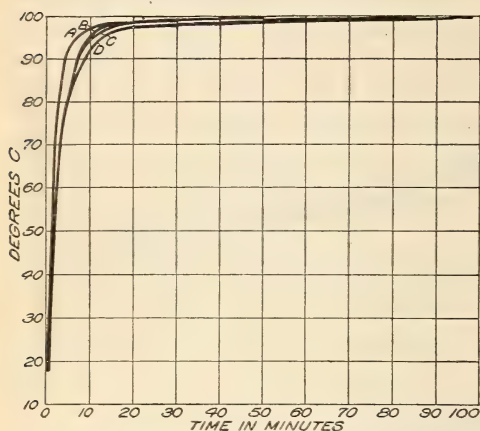


FIG. 56.—Diagram showing the effect of the first processing of different vegetables upon the rate of change of temperature. These curves were plotted from readings made at intervals of 1 minute. A, Soy beans; B, pumpkin; C, apple; D, sweet potatoes.

material was converted into a starch jelly by the cooking out of the starch during the processing, so that during the second processing the heat passed to the center only by conduction.

In the case of the soy beans the same change of rate of rise in temperature is noted, though the material that changed the viscosity of the liquid filling the interspaces between the beans was protein, and not pectin or starch.

As heretofore noted, any material which alters the viscosity of the liquid fill-

ing the interspaces between the pieces of material will affect the rate of change of temperature in the can. It may depend upon the going into solution of pectins, starch, proteins, or any other mucilaginous material.

If sweet potatoes or pumpkins are ground in a food chopper and packed closely in the cans, there is no difference in the first and second heating. If the material at the outset is of such a nature that all convection is stopped, then the going into solution of starch or protein has little effect upon the temperature changes in the can.

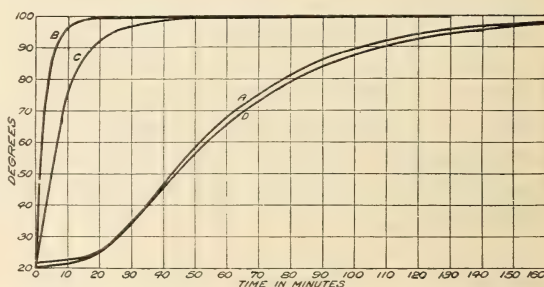


FIG. 57.—Diagram showing the effect of the second processing of different vegetables upon the rate of change of temperature. Curves A and D were plotted from readings made at intervals of 5 minutes; curves B and C were plotted from readings made at intervals of 1 minute. A, Soy beans; B, pumpkin; C, apple; D, sweet potatoes.

Any change in the material which affects the freedom of convection affects the rate of temperature change. It may be the solution

of some viscous substance, as in the soy beans; or it may be simply a compacting of the material, as happens sometimes in the case of the leafy vegetables; or it may be the evaporation of the liquid, as might happen sometimes in glass where an absolutely tight closure can not be made.

SUMMARY.

(1) The mercury thermometer is sufficiently accurate for practical work in the determination of temperature changes in the canning of food materials if it is properly calibrated and standardized.

(2) A satisfactory apparatus has been devised for measuring the temperature changes at the center of the can during the processing period and the subsequent cooling, which permits the use of the mercury thermometer both in the water bath and in the steam retort.

(3) In a can packed with material having an interspace filled with a free liquid, as in string beans, the rate of change of temperature at the center of the can is very rapid, and in materials of a heavy or pasty nature, as in sweet corn, the rate is very slow unless mechanical agitation is employed.

(4) In canned materials the character of the pack and the composition of the material very largely determine the rate of change of temperature in the can. The fineness of division and compactness of the material and the amount and viscosity of the free liquid are the factors which influence the rate of change of temperature. Variations in the composition of the material, however, have very little effect if the consistency of the material is such that no convection can occur.

(5) Sodium chlorid has very little direct effect upon the rate of change of temperature in the can. Dilute sugar solutions have only a small effect, but the concentrated solutions have a considerable effect in retarding the rate of change. Solutions of starch have a very marked retarding effect upon the rate of change of temperature at the center of the can. The retarding effect increases very rapidly from 2 to 5 per cent. In 5 per cent starch the consistency becomes such that all convection is stopped and the rate of change is very slow. Increasing the percentage of starch further has very little effect upon the temperature changes. Also, any other material of a viscous nature, such as protein or pectin, retards the rate of change of temperature.

(6) The glass container has a marked retarding effect upon the rate of rise in temperature in those materials in which there is a free liquid, as in string beans, but is of little importance in materials of a heavy consistency, such as sweet corn. On the other hand, glass cools faster in the air than tin, owing to its greater power of radiation.

(7) Differences in the diameter of the container are of much less importance in those materials in which there is a free liquid than in materials of heavy consistency. Thus there need be little difference in the processing period of No. 2 and No. 3 tin cans of string beans, but there must be considerable difference in the processing period of No. 2 and No. 3 tin cans of sweet corn.

(8) The temperature of the bath or retort is reached in the container in approximately the same time, whether the processing temperature is 100°, 109°, 116°, or 121° C. Tomatoes are a striking exception to this rule, because the higher temperatures break down the tissues of the fruit.

(9) The difference in the rate of cooling in the air and water is very marked. In materials having a free liquid the cooling is exceedingly rapid, as in string beans, but is considerably slower in materials having a heavy consistency, as in sweet potatoes. Cooling in air is always very much slower than cooling in water.

(10) Since a steam-tight closure in glass containers can not be made, any temperature above 100° falls to 100° as rapidly as the temperature of the retort, so that the temperature is always 100° or below when removed from the retort.

(11) In the intermittent process, the first processing period may or may not affect the rate of temperature change in the second processing period, depending upon the composition and nature of the material. Any change during the first processing period which interferes with convection retards the rate of change of temperature during the second processing period. This change may be the simple compacting of the material, the going into solution of starch, protein, pectin, or any other mucilaginous material. If the material at the outset is such that no convection occurs, then the gelatinization of starch or other such change has very little effect upon the rate of change of temperature in the can.

(12) The fruits and vegetables as processed in these tests fall roughly into two groups, with reference to time-temperature relations. The first group consists of those fruits and vegetables packed so that there is a free liquid filling the interspaces between the pieces of material. The rate of change of temperature in this group is very rapid. The second group consists of those materials that are packed in such a way that little or no convection can occur. The rate of change of temperature in this group is very slow.

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